SINGLE CHANNEL GROUND AND AIRBORNE RADIO SYSTEM (SINCGARS) EVALUATION MODEL

DECISIONS AND DESIGNS INCORPORATED

James O. Chinnis
Clinton W. Kelly, III
Rex D. Minckler
Michael F. O'Connor

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Inquiries and comments with regard to this report should be addressed to:

Dr. Martin A. Tolcott
Director, Engineering Psychology Programs
Office of Naval Research
800 North Quincy Street
Arlington, Virginia 22217

or

Dr. Robert A. Young
Human Resources Research Office
Defense Advanced Research Projects Agency
1400 Wilson Boulevard
Arlington, Virginia 22209

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by

James O. Chinnis, Clinton W. Kelly III
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DECISIONS AND DESIGNS, INC.

Suite 100, 7900 Westpark e
McLean, Virginia 2210.
(703) 821-2828

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SUMMARY

Introduction. This report describes the development, validation, and utilization of a multi-attribute utility model and a probabilistic cost model for use by the SINCGARS Special Task Force (STF) in evaluating the military utility and cost of a series of alternative radio systems. These models were programmed to be interactive and were made available to the SINCGARS STF in order to permit additional analyses. A separate report was submitted to the SINCGARS STF on the development of these models. The major difference between that report and this report was the inclusion of appendices in the SINCGARS STF report providing more detailed information with respect to such factors as utility functions, importance weights, values of system parameters, and technical performance characteristics.

Background and Approach. The SINCGARS Special Task Force was established by the Army Chief of Staff for the purpose of defining and recommending an optimum solution for meeting the Army's requirement to ensure that a prescribed level of suitable Very High Frequency (VHF)-Frequency Modulated (FM) Combat Net Radios (CNRs) will be available in the Army inventory in the post-1980 time frame. To this end, the SINCGARS STF defined the following four alternative courses of action for comparison/evaluation with respect to satisfying the Army's requirements for CNRs:

- Alternative 1. Retain the current VHF-FM CNRs (which consist of three families of radios) with minor product improvements.

- Alternative 2. Develop and ultimately procure a product-improved version of the current VHF-FM combat net radios that will operate with a 25 KHz channel spacing.

- Alternative 3. Continue development and ultimately procure Radio Set, AN/URC-78.

- Alternative 4. Develop and ultimately procure a new family of VHF-FM combat net radios.

The objectives of the research described in this report were to:

- Develop and test a multi-attribute utility model to be used to assist the SINCGARS STF of the U.S. Army in evaluating the military utility of alternative Combat Net Radio configurations.

- Evaluate the hardware cost estimates of Alternatives 2, 3, and 4 utilizing an interactive Monte Carlo program.

Of particular importance during the development of the multi-attribute utility model was the need to provide an analytic tool which would accept "last minute" changes in data and would also enable a user to conduct "what if" analyses on an interactive basis. A multi-attribute utility model was developed which would systematically quantify the utility of alternative radio systems. The model utilizes as inputs the technical performance characteristics of a radio system. A hierarchical structure consisting of several levels was developed, starting with military utility and partitioning this into major dimensions of utility, e.g., technical system utility and operational acceptability. These dimensions were further sub-divided into sub-dimensions which, in turn, were further partitioned--each partition becoming more specific until a level was reached at which one or more technical performance characteristics served to describe each of the sub-dimensions. The military utility for different levels of each of the performance characteristics was established by assessing a utility function over the relevant range of that characteristic. The relative importances of the different performance characteristics were assessed by assigning relative importance weights. This assignment of weights was accomplished for the components of each level of the hierarchy. The procedures for assignment depend upon how the components combine to determine system utility at the level in question. Combination rules are additive for components which independently contribute to the utility at a given level and are multiplicative, if the contribution of one or more components at a given level depends upon the value of one or more other components at that level.

The resultant structure thus systematically combined expert judgment and technical performance characteristics to provide a model which accurately aggregated the actual measures of the performance characteristics of a particular system so as to yield a measure of the military utility of the system.

The resultant model was subjected to both internal and external sensitivity analyses to ensure insensitivity to minor variations in weights and sensitivity to different alternative systems. The model was then employed to evaluate the four alternative radio systems. Also evaluated was the Korean War System (KWS), which served as a point of reference for comparison of utilities.

In the evaluation of the 15-year life cycle cost estimates of Alternatives 2, 3, and 4, the purpose of the Monte

Carlo program which was developed and used was to combine the probability distributions for the dollars of average unit of cost ($AUC) of each radio and its ancillary component for each platform (manpack, vehicular, and airborne) in proportion to the Authorized Acquisition Objectives (AAOs) of those radios and components. The outputs of this Monte Carlo program were:

- A probability distribution for the $AUC of each alternative radio system by platform.

- A probability distribution for the $AUC of each of the radios and their ancillary components by platform.

Technical Implications. Having structured and tested the SINCGARS Evaluation Model as previously described, the four alternative systems and the Korean War System were evaluated. The results are summarized in the table below.

A SUMMARY OF THE MILITARY VALUES OF OF ALTERNATIVE RADIO SYSTEM CONFIGURATIONS

Major Dimensions of Value	Alternative Radio System Configurations				
	Korean War System (KWS)	Current System (Alt. 1)	Product-Improved System (Alt. 2)	Developmental System (Alt. 3)	Conceptual System (Alt. 4)
Operational Acceptability	.32	.69	.73	.74	.80
Technical System Utility	.03	.34	.39	.67	.65
Overall Military Value	.17	.51	.56	.71	.72

*Assuming that operational acceptability and technical system utility are weighted equally in determining overall military value.

The results indicate that Alternatives 3 and 4 are superior to Alternatives 1 and 2 in terms of military value or benefit, mainly due to differences in technical system utility. Further examination of the results indicated that this superiority with respect to technical system utility is due to a significant improvement with respect to both dependability and technical performance. Technical system utility is a multiplicative combination of these two factors.

Alternatives 1 and 2 are both far superior to the Korean War System (KWS); however, Alternative 2 is only slightly superior to Alternative 1 with respect to technical system utility and operational acceptability.

With respect to the Monte Carlo evaluation of hardware cost estimates, a summary of the most likely $AUC for the three alternative systems by platform is provided in the table which follows:

A SUMMARY OF THE MOST LIKELY $AUC BY ALTERNATIVE AND PLATFORM

Platform	Most Likely $AUC of Alternative Systems 2	3	4
Manpack	$1090	$1590	$1550
Vehicular	3190	2980	2570
Airborne	3980	1990	1970

Combining the foregoing results of the evaluation of the military utility or benefit of the alternative radio systems with the results of the evaluation of hardware cost estimates, the following conclusions were reached with regard to the relative cost/benefit merits of the alternative systems:

- Inasmuch as Alternative 2 was far more expensive than either Alternative 3 or Alternative 4, the latter two alternatives are better options from a combined cost/benefit point of view.

- Because Alternative 4 has a lower hardware cost than Alternative 3, and the military values of the utilities of Alternative 3 and 4 are approximately equal, Alternative 4 is considered to be the most cost/beneficial option. However, this conclusion must be qualified somewhat by the fact that the employment of two receiver/transmitters

with Alternative 3, rather than an auxiliary receiver, increases its average unit cost ($AUC) by about $500.00. If this situation were rectified, Alternative 3 would compare quite favorably with Alternative 4 from a cost/benefit standpoint.

The foregoing results were based upon the information which was available with regard to the various alternative radio systems. The flexible structure of the SINCGARS Evaluation Model, however, has enabled the SINCGARS STF to continue to use the model:

- With new or modified input data.

- To conduct "what if" analyses on an iterative, interactive basis in response to queries that have been received.

In so doing, the SINCGARS STF has attained an increasingly better understanding of all of the factors involved in the evaluation of the alternative systems and a greater degree of confidence in the recommendations which they have made based upon their use of the model.

Methodological Implications. The following two additional observations are also important from the standpoint of decision analytic theory:

- The evaluation of alternative systems is very closely related to system design, so the evaluation model must be very flexibly structured with respect to possible changes in inputs in order to permit meaningful "what if" analyses. For example, the range of a technical performance characteristic over which a utility function is assessed should not be the entire physical performance range of a general system, for this will cause the model to be quite insensitive. If specific alternatives which will not change are to be evaluated for purpose of choosing among them, the range of a performance characteristic should be the range for the alternatives under consideration. However, when the designs of developmental or conceptual systems are being evaluated, then the range of a technical performance characteristic over which a utility function is assessed should reflect the minimum feasible to the maximum feasible performance range of those systems.

- Close attention must also be given to the definition of scenarios as conditioning variables in the

evaluation of alternative systems. The scenarios should be so defined that not only will they be representative of the situations in which the alternatives will operate and thus permit the assessment of the expected utilities of all of the alternative systems, but also they must serve to discriminate clearly among the alternative systems. These goals are not usually compatible, and an in-depth analysis of which goal to pursue must be accomplished in order to decide upon the definition of scenarios.

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THE DEVELOPMENT OF A SINGLE CHANNEL GROUND AND AIRBORNE RADIO SYSTEM (SINCGARS) EVALUATION MODEL

1.0 INTRODUCTION

The Single Channel Ground and Airborne Radio System (SINCGARS) Special Task Force (STF) was established on December 2, 1974 in accordance with the Army Chief of Staff's Memorandum (CSM) 74-15-101, dated November 21, 1974. The charter for the SINCGARS STF:

- Defines SINCGARS "as a radio communication system designed primarily to be organic to and operated by the combat arms. The system will be used by the Army in the field where its employment is required and cost effective."[1]

- Describes the mission of the SINCGARS STF in terms of establishing "the management and technical base, under the provisions of Army Regulation 1000-1, for a cohesive, integrated, secure communications system as specified in the approved Required Operational Capability (ROC) for the VHF-FM portion of the SINCGARS. This effort will consider the impact or relationship to all single channel communications systems designated to be organic to and operated by the combat arms in the post-1980 time frame."[1]

Within the context of this mission statement, the objective of the SINCGARS STF may be further described in terms of defining and recommending an optimum solution for meeting the Army's requirement to ensure that a prescribed level of suitable combat net radios (CNRs) will be available in the Army inventory in the post-1980 time frame. To this end, the SINCGARS STF identified the following four alternative courses of action with respect to satisfying the Army's requirements for CNRs:

- Alternative 1. Retain the current VHF-FM CNRs (which consist of three families of radios) with minor product improvements.

- Alternative 2. Develop and ultimately procure a product-improved version of the current VHF-FM combat net radios that will operate with a 25 KHz channel spacing.

- Alternative 3. Continue to develop and ultimately procure Radio Set, AN/URC-78.

[1]Charter for the Department of the Army Single Channel Ground and Airborne Radio Subsystem (SINCGARS) Special Task Force (STF), Office of the Chief of Staff, Department of the Army, February 20, 1975.

- Alternative 4. Develop and ultimately procure a new family of VHF-FM combat net radios.

In order to obtain a better understanding of the nature of the foregoing alternatives, it is desirable to know more about the types of radios involved in each alternative. Based upon information provided by the SINCGARS STF, the types and general quantities of radios may be summarized as follows:

- Alternative 1: Current Series of CNRs. As previously indicated, the current series of CNRs actually consists of three more or less independent families of radios, which are the AN/PRC-77 (a manpack radio), the AN/VRC-12 (a vehicular radio), and the AN/ARC-114 (an airborne radio). Although these families of radios all operate in the 30-76 MHz frequency band, they have been developed independently to satisfy specific user needs for manpack, vehicular and airborne communications. The radios have been modularly constructed to allow for improved maintenance and growth capabilities, but no commonality of modules exists among these radio families. The three families of radios may be further described as follows:

    - AN/PRC-77. This manpack radio provides a short-range, frequency modulated (FM) voice communications capability for the Army in the field. The AN/PRC-77 became operational in 1968 as a result of a product improvement program of the AN/PRC-25. Three omni-directional antennas can be used with the AN/PRC-77; namely, a 3-foot semi-rigid flexible steel tape antenna (AT-892/PRC), a 10-foot foldable antenna (AT-271A/PRC), and a telescoping 3 to 10-foot antenna (AS-2109). With the addition of an Amplifier Power Supply Group (OA-3633), Vehicular Mounting (MT-1029), and Vehicular Antenna (AS-1729), the AN/PRC-77 can be configured for vehicular use. As such, it is redesignated the AN/VRC-64. A configuration which allows for both manpack and vehicular operation is the AN/GRC-160. A more detailed description of the technical characteristics of this manpack radio is provided in Appendix E.

    - AN/VRC-12. This family of vehicular radios became operational in 1962 and consists of eight radio configurations: the AN/VRC-12 and the AN/VRC-43 through AN/VRC-49--which provide short-range vehicular communications

for the Army in the field. All configurations consist of various combinations of the three major components, which are the Receiver/ Transmitter (RT-246 with 10 push button presets), the Receiver/ Transmitter (RT-524 with a built-in loudspeaker), and the Auxiliary Receiver (R-442). Common modules are utilized for all three major components, and all configurations may be readily adapted for use in any tracked or wheeled vehicle or they can be used alone or in conjunction with ancillary vehicular radio intercommunications equipment, such as the Intercommunications Set, AN/VIC-1(U). All AN/VRC-12 family configurations use the AS-1729/VRC, 10-foot, omnidirectional vehicular whip antenna. A more detailed description of the technical characteristics of this vehicular radio is provided in Appendix E.

- AN/ARC-114. This airborne radio, which was operationally deployed in 1970, is a modularly constructed, securable VHF-FM radio receiving and transmitting set used for Army tactical aircraft command and control communications. It is interoperable with the AN/PRC-77 and AN/VRC-12 families of radios and can be tuned to any one of 920 channels. In addition, it has a fixed tuned guard receiver. The AN/ARC-114A provides a homing capability when used with the FM Homing Antenna System and Heading-Radio Bearing Indicator, ID-1351 1A. The radio set has no organic antenna because the antenna is integral to the aircraft and varies with the type of aircraft. A more detailed description of this airborne radio is provided in Appendix E.

- Alternative 2: Product Improvement of the Current Series of CNRs. As the term product improvement implies, the current series of CNRs will simply be improved in terms of reliability. Complete modification of the radios to meet the SINCGARS-V Required Operational Capability (ROC) characteristics is not contemplated. Available channels will increase to 1840--spaced at 25 KHz. A more detailed description of the technical characteristics of the product-improved CNRs is provided in Appendix E.

- Alternative 3: Developmental Radio Set, AN/URC-78. This radio, which uses state-of-the-art technology to include Large Scale Integration (LSI), has taken a system approach to the Army VHF-FM tactical communications requirements. It provides modules

to satisfy the various manpack, vehicular and airborne radio requirements. The basic module is the receiver/ transmitter (R/T) which is common to all configurations. Appliques and adapters in the form of power amplifiers, antennas, and vehicular mounts are used to configure the radio o meet specific requirements. Unique features of the AN/URC-78 include:

- All electronic channel selection
- Four preset channels
- Automatic, continuous antenna tuning
- A low antenna silhouette, involving a 1 to 4-foot manpack whip and a 6-foot vehicular whip antenna
- Selectable 25 KHz/50 KHz channel spacing

The AN/URC-78 is compatible with the current families of VHF-FM CNRs, their intercommunications systems, radio/wire integration (R/WI) systems, and other accessories. The AN/URC-78 radio system has no inherent electronic counter-countermeasure (ECCM) capabilities other than operator-applied techniques, such as alternate frequency selection. Additional details with respect to the technical characteristics of this radio are provided in Appendix E.

- Alternative 4: A New CNR. A new CNR will involve the application of the latest technology to provide the best technical approach (BTA) to the problem of ensuring that the Army in the field will have the most suitable VHF-FM CNR in the post-1980 period of time. Among the other improved features of this radio will be an ECCM capability for those manpack, vehicular, and airborne modules which require such a capability. A more detailed description of the technical characteristics of this new CNR is provided in Appendix F.

The primary implication of the foregoing summary of the various types of radio systems involved in the four alternative courses of action identified by the SINCGARS Special Task Force is that:

- There are, in fact, different types of radio sets with different performance/physical characteristics and different required quantities to be considered in connection with Alternatives 1 and 2. Judgments with respect to the utility of the various performance/physical characteristics of the radio sets in Alternatives 1 and 2 therefore reflect composite systems. Moreover, it should be noted that the overall utility values for each of the various

alternatives reflect the combined values for the three different types of platforms.

2.0 PROJECT OBJECTIVE

The objective of the research reflected in this report was to develop and test a multi-attribute utility model which might be used to assist the SINCGARS STF in evaluating the military utility of alternative CNR configurations. Of particular interest in the development of this model was the need to provide an analytic tool which would:

- Provide a comprehensive evaluation of the four alternatives.

- Be able to accommodate new alternatives as well as modifications to the given alternatives.

- Accept "last minute" changes in data and diverse expert judgments.

- Enable a user to conduct "what if" analyses on an iterative, interactive basis.

3.0 GENERAL STRUCTURE OF THE MODEL

3.1 Approach

A variety of procedures might be employed for the purpose of evaluating alternative systems -- in this case, alternative radio systems. These procedures could range from the elicitation of overall (global) judgments with respect to the alternative systems from a group of experts to the use of very complex computer simulations. The former approach tends to be too simplistic and subject to many inherent difficulties --one of which is that the problem is far too complex for accurate, global judgments -- and the latter, although often used, suffers from the shortcoming that system performance may not be directly related to measures of worth or utility for mission performance.

The approach adopted during this project was to develop, test, and utilize on an iterative basis what is described as a multi-attribute utility model, which decomposes the problem in such a way that independent judgments may be made with regard to individual components of the problem and subsequently aggregated to provide an overall judgement using a formal mathematical structure which can be implemented on an interactive computer. The model utilizes utilities derived from user requirements. Such utilities are supplied by members of the user community. The model is tied to the technical performance characteristics of a system, thus emphasizing how a system performs as opposed to how such performance is achieved.

The advantages of such a model are two-fold, namely:

- It permits an individual who is an expert in a particular area to make judgments which involve his particular area of expertise rather than making an overall judgment of worth which may fall outside his area of expertise.

- Disaggregating the judgments of individual experts provides a clearly auditable trail leading from measures of system performance to measures of benefit or utility. Thus the judgments are public rather than private and are subject to screening.

In other words,

> Being able to separate overall judgments into (explicit) components in this manner can provide a manager with valuable information about the relative importance of various attributes of a product (or system). It can also provide a manager with valuable information about

the value of various levels of a single attribute. Indeed, some models can even estimate the (implicit) trade-offs consumers (users) make when they evaluate several attributes together.[2]

Thus, although a multi-attribute utility model (such as will be described in this report) is dependent upon the expert judgment of the user community, it is objective in that the linkages between data and conclusions are identified and clearly visible.

At the very outset, it is important to differentiate between the multi-attribute utility model which has been developed and other forms of models which are, in fact, simulations of the system being developed. On the one hand, the multi-attribute utility model shows how changes in system parameters, which describe system performance and acceptability, enhance or reduce the attractiveness of a proposed system for the user. A simulation model, on the other hand, generally shows how changes in technological characteristics modify the technical performance of the system.

3.2 Expert Judgments

As may be appreciated, a crucial step in developing a multi-attribute utility model involves the identification of the experts whose judgments will serve as inputs during the modeling process. The development of the structure of the SINCGARS model and the formulation of parameter ranges, utility functions, rules of combination and importance weights were accomplished during a series of intensive working sessions with SINCGARS STF personnel representing the user. The judgments of these individuals were further refined by using mission and performance envelopes provided by the Army Training and Doctrine Command (TRADOC).

3.3 An Overview of the Structure of the Model

The first step in developing the SINCGARS Evaluation Model was to establish a logical structure relating physical system parameters to military value. This structure is a model describing how the physical and performance parameters of a radio system are translated into measures of utility reflecting how well that system accomplishes its military mission. Although a variety of structural decompositions are possible, assessment of the military value of a system is usually decomposed into an assessment of technical system utility (i.e., how well the system functions as a radio) and an assessment of operational acceptability (i.e., how attractive the system is from an operational point of view). The

[2] "New Way to Measure Consumers' Judgments," Paul E. Green and Yoram Wind, Harvard Business Review, July-August 1975. Words in parenthesis have been added by the authors of this report.

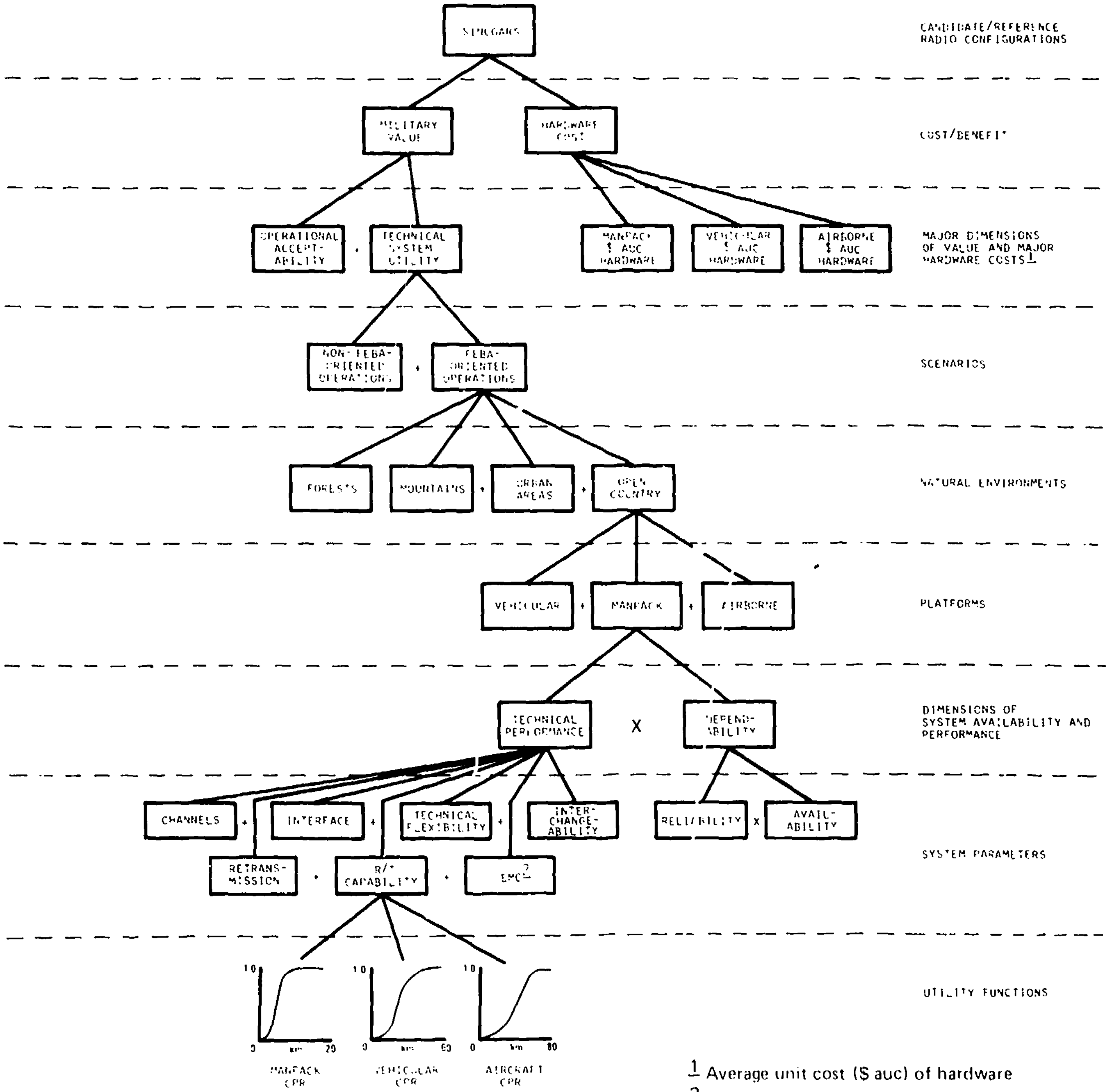
assessments of these two dimensions are ultimately combined to provide a measure of military value which may then be related to a measure of the cost of the particular system.

In developing the structure of this multi-attribute utility model, the dimensions of technical system utility and operational acceptability are further decomposed into sub-dimensions. For example, technical system utility may be decomposed into technical performance (i.e., how well the system performs) and dependability (i.e., how reliable/available the system is considered to be). Each of these dimensions may be further decomposed so that, as the decomposition continues, a hierarchy consisting of several levels of sub-dimensions or factors is created -- each level becoming more specific than the previous level. Decomposition of the sub-dimensions is complete when the sub-dimensions may be specified or quantified by relating them to one or more technical performance characteristics of the system. For example, the receive/transmit (R/T) capability of a SINCGARS may be quantified in terms of the communications planning range (CPR) by radio platform (i.e., manpack, vehicular, and airborne). The lowest levels of the model are therefore actual measurable system characteristics, and the overall structure of the model serves as a mechanism for combining the information obtained with regard to these paramters into measures of utility.

The general structure of the SINCGARS Evaluation Model which was developed, highlighting technical system utility, is shown in Figure 3-1. The further decomposition of technical performance into its constituent sub-dimensions is reflected in Figure 3-2. A similar diagram of the structure of the SINCGARS Evaluation Model, highlighting operational acceptability, is presented in Figure 3-3. As may be observed in this figure, the physical characteristics dimension of operational acceptability has been further decomposed into such sub-dimensions as weight, size, form factor, visual detectability, human factors engineering, and security features. Moreover, the sub-dimension pertaining to size has been quantified in terms of the volume (cubic inches) of the radio by platform (i.e., manpack, vehicular, and airborne). The decomposition of the other dimensions of operational acceptability (viz., flexibility, survivability, support requirements and transmission quality) is reflected in Figures 3-4, 3-5, 3-6 and 3-7.

3.4 Conditioning Variables of the Model

Between the level of the major dimensions of value and that of the system parameters/sub-parameters in Figures 3-1 and 3-3 are three levels identified as scenarios, natural environments, and platforms. The variables described at each of these intervening levels are not sub-dimensions of the major dimensions of value, nor are they system parameters/sub-parameters. Instead, they are conditioning variables

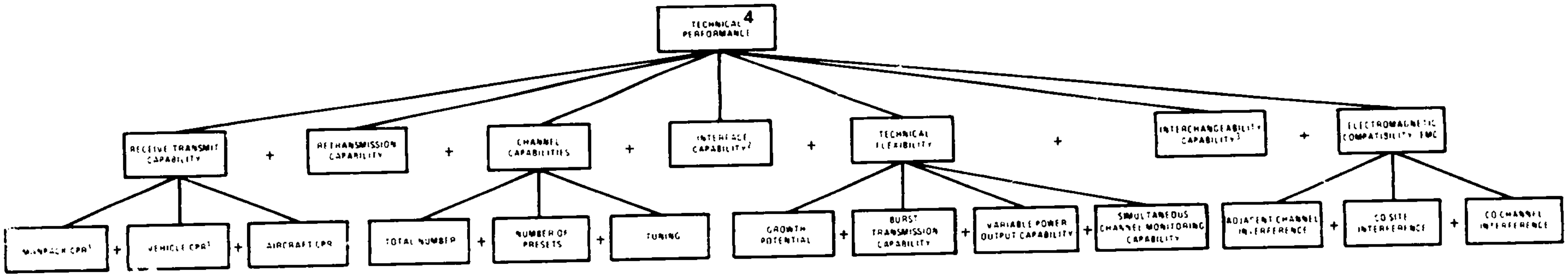


1 Average unit cost ($ auc) of hardware

2 Electromagnetic compatibility

Figure 3-1

THE GENERAL STRUCTURE OF A SINCGARS EVALUATION MODEL HIGHLIGHTING TECHNICAL SYSTEM UTILITY

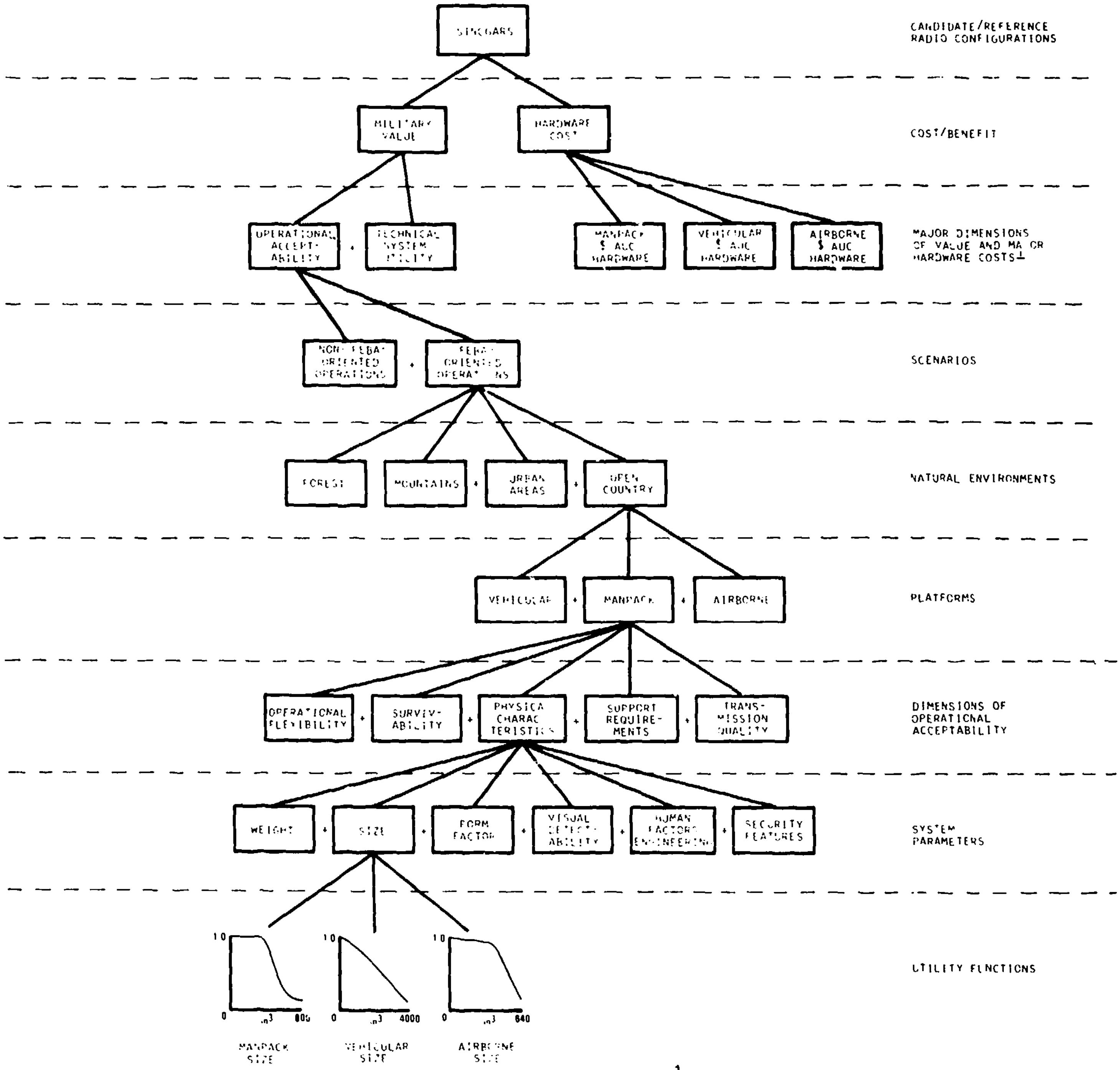


1 Communications planning range
2 With tactical data and automatic switching systems
3 Manpack to vehicle to aircraft

4 The sub dimensions in this figure appear in a somewhat different order than in Figure B-1 for convenience in presentation. Therefore, the utility functions are not numbered sequentially.

Figure 3-2

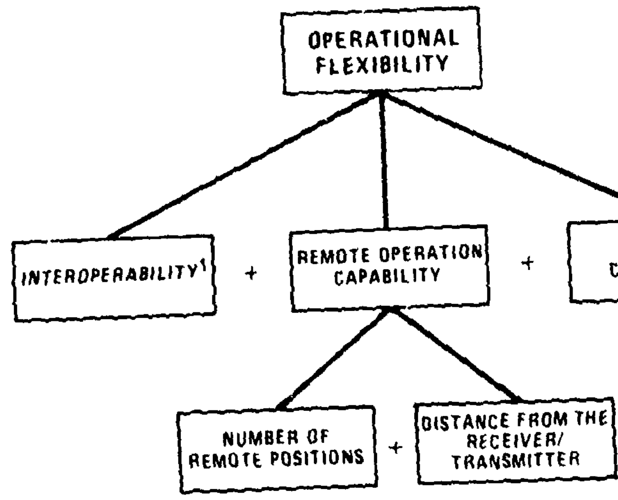
TECHNICAL PERFORMANCE



1 Average unit cost ($ auc) of hardware

Figure 3-3

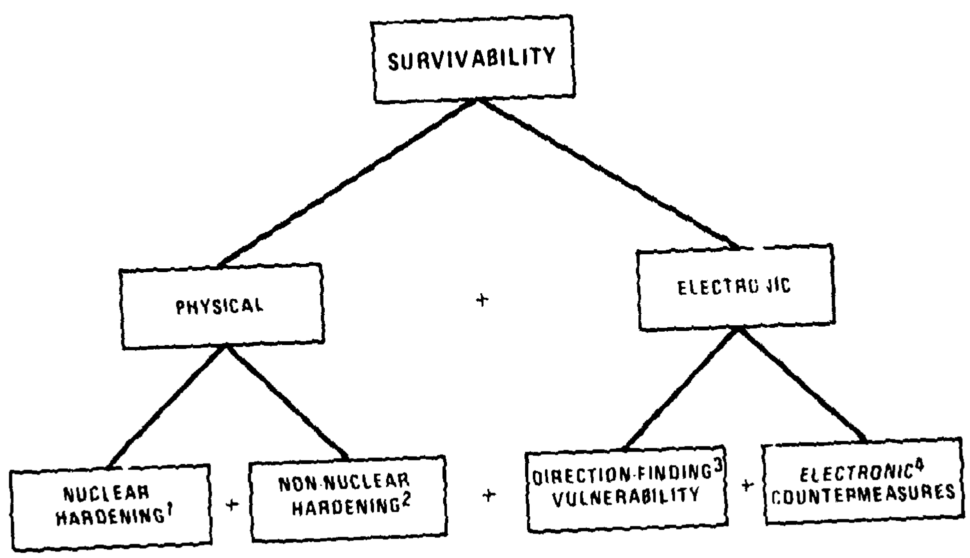
THE GENERAL STRUCTURE OF A SINCGARS EVALUATION MODEL HIGHLIGHTING OPERATIONAL ACCEPTABILITY



[1] With other Service, older and Allied radios.

Figure 3-4

OPERATIONAL FLEXIBILITY



[1] Reflecting hardening against radiation, thermal, and blast effects

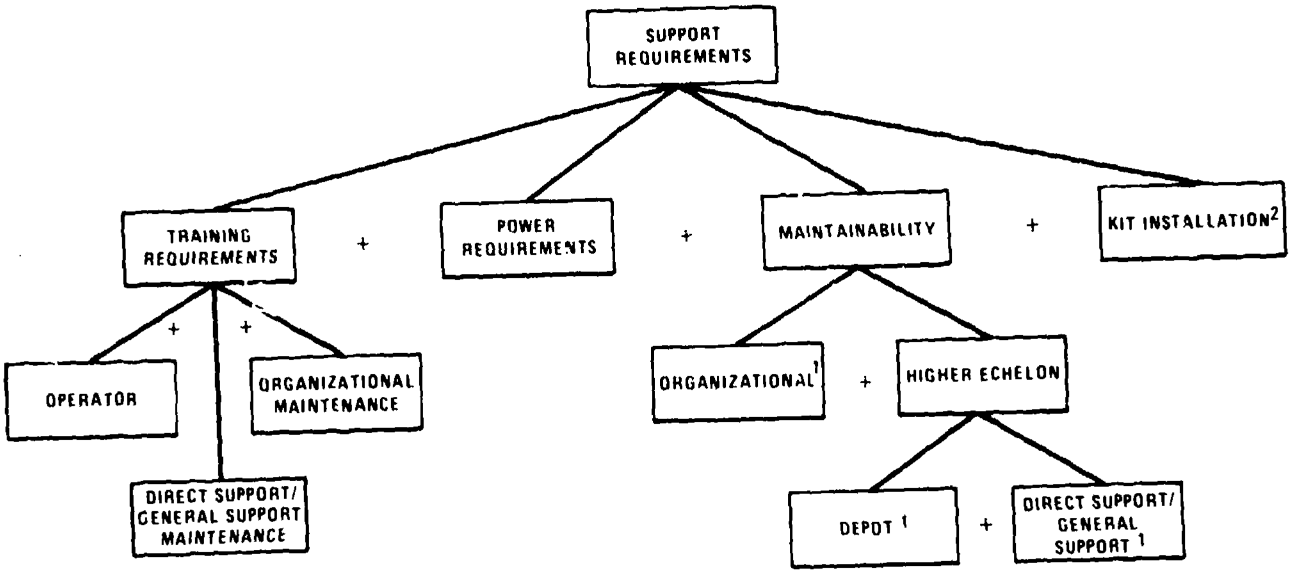
[2] Reflecting receiver/transmitter case penetration protection against projectiles (small arms, shrapnel, etc.)

[3] In terms of the effective radiated power of the transmitter

[4] Electronic countermeasures, in terms of anti-jamming protection

Figure 3-5

SURVIVABILITY



[1] Reflecting mean time to repair (MTTR)

[2] Reflecting the time required to mount the radio in a vehicle or aircraft

Figure 3-6

SUPPORT REQUIREMENTS

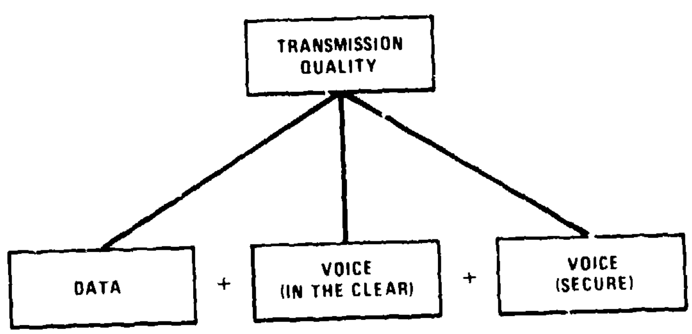


Figure 3-7

TRANSMISSION QUALITY

upon which, for any SINCGARS alternative, the values of the system parameters/sub-parameters and their associated utilities will depend. In other words, the performance and utility of a SINCGARS alternative will vary as a function of the situation or scenario in which it is employed, the natural environments in which it will perform, and the platform on which it is mounted. In this model, the scenarios have been broadly defined as follows:

- Forward edge of the battle area (FEBA) oriented operations, in which there is a generally defined, continuous front which moves forward or backward as a battle/campaign progresses.

- Non-FEBA oriented operations, in which the tactical situation is quite fluid and the front is generally non-continuous.

The second conditioning variable, which reflects the various environments, has been broadly defined as follows:

- Forested areas, such as might be illustrated by the Bavarian area of southern Germany in which communications, ground mobility, and visual observation are generally inhibited by the heavy growth of trees and underbrush.

- Mountainous areas, such as might be represented by the precipitous terrain in eastern/central Korea and parts of the Middle East, in which communications, ground mobility, and visual observation are generally inhibited by intervening land masses.

- Urban areas, such as those which cover a considerable portion of the landscape of central Germany and generally inhibit communications, ground mobility, and visual observation.

- Open country, such as the central plains of Germany and France and parts of the Middle East where there is little degradation of communications and visual observation due to terrain and ground mobility is generally excellent.

The third and final important conditioning variable, as a function of which the performance and utility of a radio system will vary, is the platform on which the radio will operate. The three categories of platforms are generally described as follows:

- Manpack, which indicates that the normal means of transporting/operating the radio is the individual soldier(s).

- Vehicular, which indicates that the radio is normally mounted in/operated from a wheeled or a tracked vehicle.

- Airborne, which indicates that the radio is normally mounted in/operated from an Army helicopter or fixed wing aircraft.

As may be readily observed in Figures 3-1 and 3-3, the two scenarios, four environments, and three categories of platforms provide a total of 24 (i.e., 2x4x3) different paths or single threads from the level of the major dimensions of value to that of the system parameters. The values of the system parameters are determined for each of the 24 threads and then the utility over each parameter and sub-parameter is assessed, conditional upon the particular thread that is being evaluated. Ultimately, an overall utility for a given system may be obtained by combining the utilities associated with each of the 24 threads.

3.5 Specification of the Sub-Dimensions of the Model

As previously indicated on pages 7 and 8, the sub-dimensions at the lowest levels shown in Figures 3-1 and 3-3 are specified in terms of one or more system parameters. For example,

- The receive/transmit (R/T) capability of a SINCGARS is specified, as reflected in Figure 3-2, in terms of the communications planning range (CPR) by platform.

- The channel capabilities of a SINCGARS are specified in terms of the:

  - Total number of channels available
  - Number of preset channels available
  - Tuning capabilities

In other cases, the sub-dimensions are specified by the responses to one or more questions. For example,

- Burst transmission capability under technical flexibility in Figure 3-2 is described by a "yes" (indicating that the radio has the capability and is therefore given a value of 1.0) or a "no" (indicating that the radio does not have the capability and therefore is given a value of 0.0).

- Interoperability under operational flexibility in Figure 3-4 is described on the basis of the degree of interoperability of a SINCGARS alternative with other related radios. There are three degrees of interoperability.

In developing the SINCGARS Evaluation Model, it was necessary to assign weights to each of the factors which entered into the model and to generate utility functions for the controllable system performance characteristics. However, before doing this, it was necessary to establish reasonable ranges for each of the system performance characteristics because the interval over which the technical performance characteristics can vary will affect both the shape of each utility function and the magnitude of the weights assigned to particular factors. For example, although a given parameter might be extremely important in principle, its importance may not change with respect to the range under consideration, and it will therefore receive a lesser weight than one whose range varies significantly for the alternative systems under consideration. The retransmission capability of a radio system is undoubtedly an important function, but if all of the SINCGARS alternatives under consideration have equivalent retransmission capabilities, then this sub-dimension should receive little or no weight in the model.

3.6 Utility Functions

Once the lowest level sub-dimensions of value have been described in terms of system performance characteristics and reasonable ranges have been established for each of these characteristics, then a utility function is assessed over the range for each of the system performance characteristics. This function assigns a utility of 1.0 to the best value in the range of the performance characteristic and 0.0 to the worst value in the range of the characteristic. All intermediate values are assigned utilities between 0.0 and 1.0. The utility function, which may be continuous (as shown in Figure 3-8) or may be discrete (as shown in Figure 3-9), serves to translate changes in the system characteristics into a measure of benefit conditioned by the particular path through the hierarchy with which a particular utility function is associated. The utility functions also provide a means of assessing the impact on the overall system performance of marginal changes in a number of technical system characteristics.

The manner in which a utility function captures the importance of a variation in performance characteristics is illustrated by means of the curves shown in Figures 3-10 and 3-11. In the case of kit installation time in Figure 3-10, an installation time of zero is, of course, ideal, but an installation time of 20 minutes still has a utility of 0.6 on a scale from 0 to 1.0. On the other hand, in the case of transmission quality in Figure 3-11, a transmission quality for data greater than 10^{-6} bits per second is good, but 10^{-4} bits per second is useless. Therefore, the latter utility

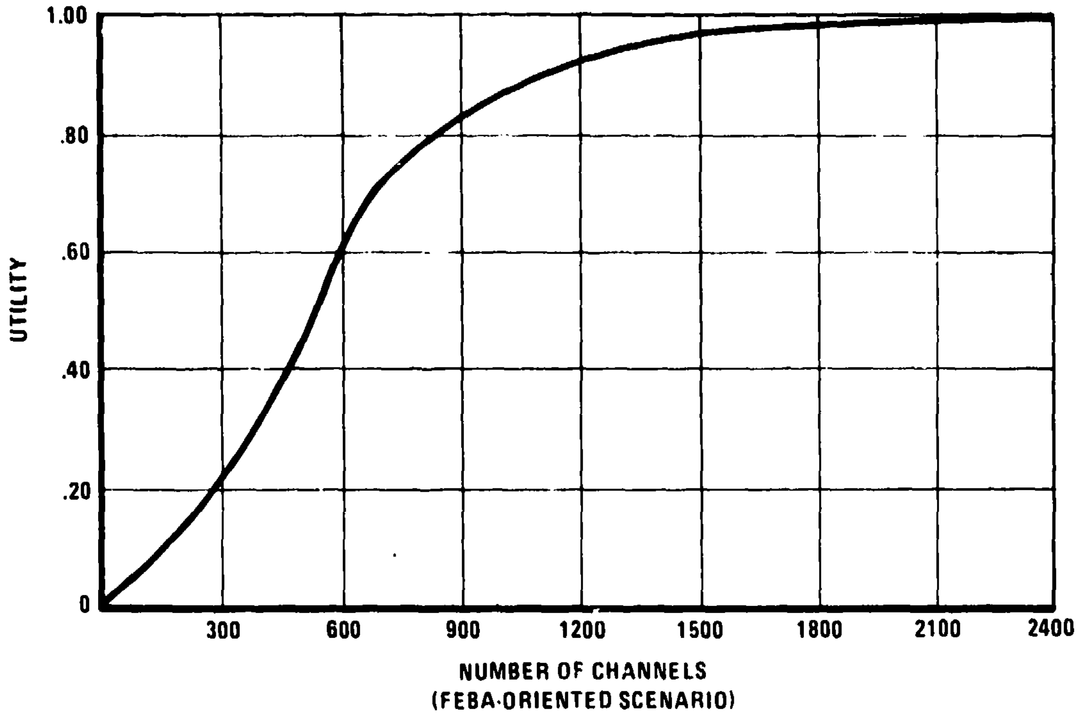


Figure 3-8
BASIC UTILITY FUNCTION FOR THE TOTAL NUMBER OF CHANNELS

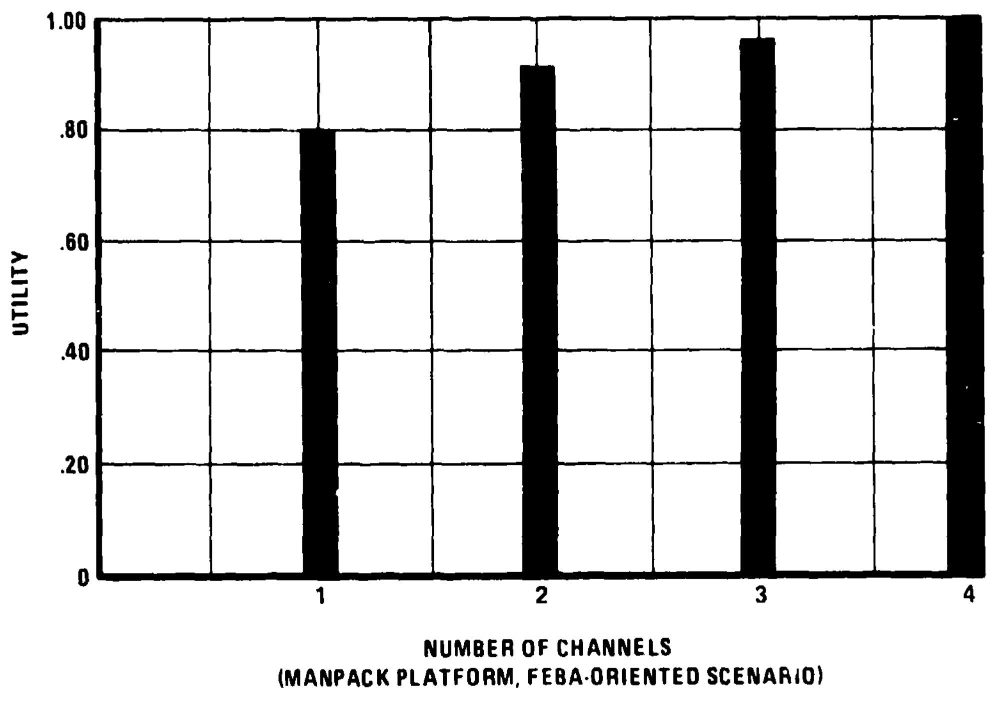
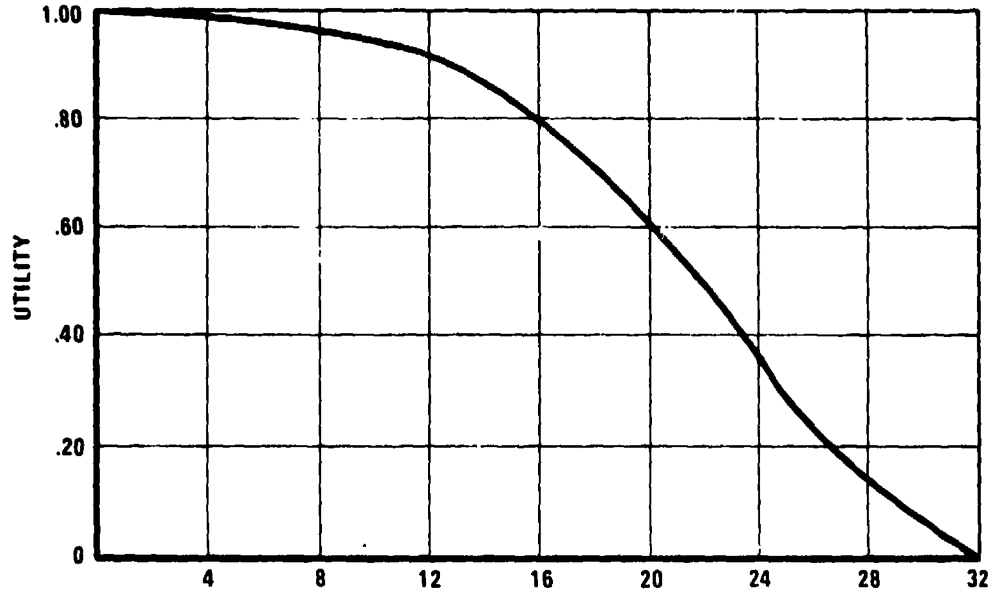


Figure 3-9
BASIC UTILITY FUNCTION FOR NUMBER OF ADDITIONAL SIMULTANEOUSLY MONITORED CHANNELS[1]

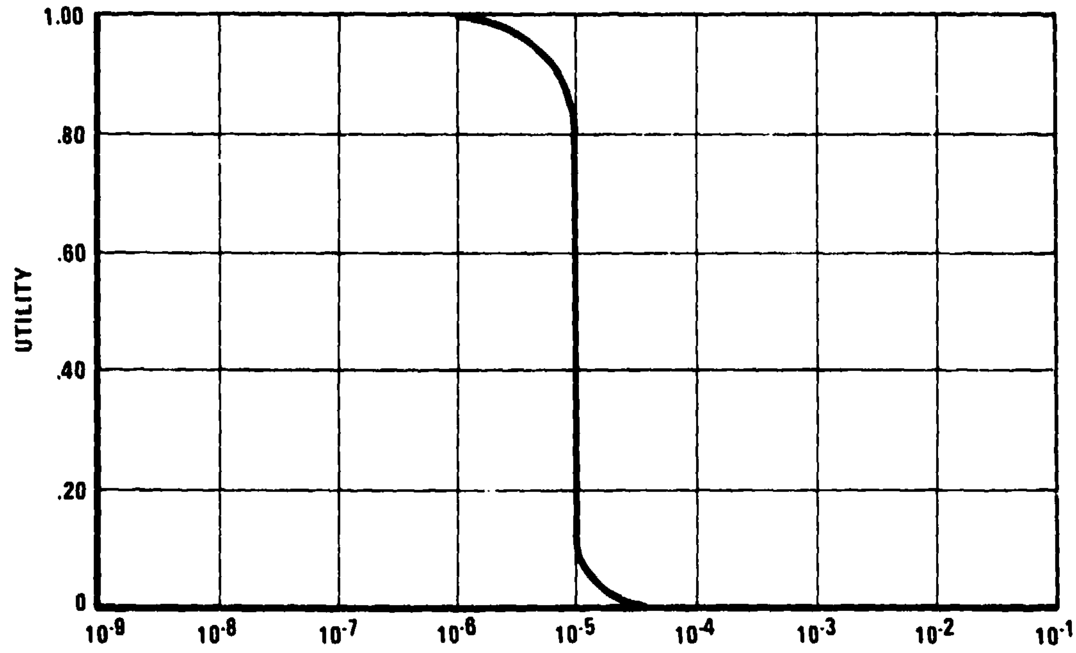
[1]Without the use of an auxiliary receiver



[1]In Aircraft Console

TIME REQUIRED TO INSTALL RADIO[1]

Figure 3-10
BASIC UTILITY FUNCTION FOR KIT INSTALLATION



*Data transmission only

BITS PER SECOND
BIT ERROR RATE

Figure 3-11
BASIC UTILITY FOR TRANSMISSION QUALITY [1]

function essentially represents a point requirement for transmission quality. The advantages of using utility functions as opposed to point requirements for the evaluation of alternative systems are that utility functions:

- Preclude the over-design of a system by explicitly acknowledging the fact that the design process is a constant trade-off between benefits received, on the one hand, and the cost of achieving those benefits, on the other hand.

- Permit identification of those areas in which requirements may be relaxed with little loss in total system utility versus those areas in which a small change in requirements may have a major impact on total system utility.

In all, there were some 94 utility functions developed for all of the system parameters used to describe the sub-dimensions of value in the SINCGARS Evaluation Model. In addition, there were almost 1300 pieces of input data required for the various system parameters/sub-parameters of the alternative systems evaluated.

3.7 Rules of Combination

The purpose of the hierarchical utility structure shown in Figures 3-1 and 3-3 is to transform technical descriptions of system performance at the bottom of the structure into a measure of military value at the top of the structure. The rules for aggregating factors within each level of the hierarchy are either additive or multiplicative, depending upon whether or not the factors contribute to overall military value in an independent or interactive manner. The interactions that are important in a utility model are value-wise dependencies--not technical system dependencies. In other words, variables can be independent in terms of their contribution to overall system utility but, due to design constraints, they interact strongly in terms of what might be realized with respect to a particular system.

At the scenario, environment, and platform levels of the model, the variables are essentially independent, and the overall utility of an alternative system increases with the utility of each variable. The variables are therefore combined additively. At the dimension/sub-dimension levels of the model, the factors are combined additively and multiplicatively. For example, as indicated in Figure 3-1, the sub-dimensions of technical performance are all additive, but the sub-dimensions of dependability are multiplicative. Furthermore, as also may be observed in Figure 3-1, the technical performance and dependability dimensions are combined multiplicatively because even a radio set with outstanding technical performance capabilities could be degraded to zero if it is undependable.

The actual rules of combination applied throughout the SINCGARS Evaluation Model are either + (additive) or x (multiplicative), as shown in Figures 3-1 through 3-7.

3.8 Importance Weights

After ranges are established for each technical parameter/sub-parameter and utility functions are developed, it is necessary to assign importance weights to each branch of the model. Two kinds of importance weights are required, depending upon the rules of combination. In the case of a set of additive factors, importance weights simply provide a means of calculating a weighted average over the factors being considered. Consequently, the importance weights assume the form of coefficients that are multiplied by the utility of the system for each of the factors, and these coefficientes sum to 1.0 across all factors within a given level of the hierarchical structure. The weight given to a particular factor reflects the relative contribution of that factor to utility for that level of the model.

In the event that factors within a given level are multiplicative (that is, they are interactive in a value-wise sense), then the measure of utility of any factor may be considered as a measure of degradation. When variables interact in this manner, importance weights have the effect of re-scaling the factors. Prior to applying a weight, the utility over one of the factors may have any value between zero and one. However, assume, for example, when this factor takes on its worst value, then the effectiveness of a system is degraded to the order of 30%. In this case, the utility, originally scaled from 0 to 1.0, would be rescaled from 0.3 to 1.0.

As previously indicated, the technical performance and dependability dimensions in the model are combined multiplicatively because an undependable, though highly operable, radio is quite useless. In the case of this model, the dependability factor continues to be scaled from 0 to 1.0 because the military value of a thoroughly undependable radio is considered to be zero.

3.9 Computer Implementation and Evaluations

Having structured the model as described in the previous sub-sections, it was programmed on a computer so that it could be utilized on an interactive, iterative basis. Although a model such as this may be substantively logical to those involved in this development, the initial results from the model, when first applied to the evaluation of

actual systems, may identify areas where modification is required. Therefore, computer implementation provides not only a capability to change the inputs to the model and rapidly obtain new results on an interative basis, but also a capability to conduct extensive sensitivity analyses both within the components of the model and with respect to the evaluation of different kinds of systems in order to identify those portions of the model which require modification.

Sensitivity analyses within the model involve an evaluation of the degree to which changes in importance weights, combination rules, and utility functions influence the output of the model. For example, to what degree does the relative utility of Alternative System 1 versus Alternative System 2 depend upon the weights assigned to a factor within the model? Sensitivity analyses external to the model provide a means of calibrating the model and involve the use of the model to compare known, well-understood alternative systems before using the model to evaluate less well understood systems. This is to say that it is useful to test the model against educated judgments with respect to the relative utility of existing systems, or components of existing systems, before applying the model to possible future systems. If the model appears to be blatantly at odds with expert judgments pertaining to the relative utility of known systems, analysis of the model should lead to the identification of the source of the disagreement and thereby facilitate modification of the model so as to bring subsequent evaluations more into line with informed judgments. It is difficult to overemphasize the importance of these kinds of sensitivity analyses in terms of both improving the evaluation model itself and developing confidence and understanding on the part of the user who intends to make recommendations based upon the output of the model.

Several sensitivity analyses were performed on the SINCGARS Evaluation Model. Internal sensitivity analyses examined the sensitivity of the model with respect to variations in importance weights. In this context, it has been found that experts consider the assessment of inter-dimensional importance weights to be more difficult than judgments with respect to intra-dimensional utility functions. This is not surprising since the inter-dimensional importance weights usually involve trading off quantities measured in different units, while intra-dimensional utility functions only involve trading off different amounts of a given dimension. Errors of judgment are therefore more likely to occur with respect to inter-dimensional importance weights. It would appear to be a reasonable assumption that, even if an expert has great difficulty in assessing weights over factors, the weights assigned should reflect the correct ordering of the factors. The limiting case of error and/or variation in weights

occurs when all weights are set equal -- in which case the order of factors collapses, for they are all equally important. Hence, the equal weighting of factors does constitute a good internal sensitivity analysis with respect to this source of error.

Table 3-1 presents the overall values of technical systems utility and operational acceptability which were generated by the model for alternative radio systems identified by the SINCGARS Special Task Force.

Table 3-1

TECHNICAL SYSTEM UTILITY AND OPERATIONAL ACCEPTABILITY WITH UNEQUAL AND EQUAL WEIGHTS

Alternative Radio Systems[1]	Technical System Utility		Operational Acceptability	
	Unequal Weights	Equal Weights	Unequal Weights	Equal Weights
KWS	.03	.03	.32	.35
1	.34	.30	.69	.60
2	.39	.34	.73	.65
3	.67	.62	.74	.66
4	.65	.59	.80	.68

[1]The various radio systems may be briefly identified as follows:
KWS - An older system, vintage of the Korean War (1950s).
1 - The current system, vintage of the 1960s.
2 - A product-improved version of the current system.
3 - A developmental system with a 4-foot antenna.
4 - A conceptual system.

The values which appear in Table 3-1 reflect the use of both unequal and equal weights at all nodes of the structure of the model. Although the actual values of the utilities of the alternative systems changed, the ordering remained the same. The values of operational acceptability are nearly equal for Systems 2, 3, and 4 with equal weights. This is because the systems do not differ greatly with respect to survivability, support requirements, and transmission quality. The main differences occur in terms of flexibility and physical characteristics, especially the latter, and these two dimensions are heavily weighted in the model. Assigning equal weights then places relatively less emphasis on them and more on dimensions where the differences are extremely small. This, of course, should and did drive the values toward equality. Even in this case, however, the ordering of the alternatives remained invariant. Thus it may be stated that the conclusions reached are insensitive to a fairly broad range of errors in weights. This is consistent with results obtained in other decision analytic studies.[3]

[3]For example, "Unit Weighting Schemes for Decision Making," by H. J. Einhorn and R. M. Hogarth in Organizational Behavior and Human Performances, pages 13 and 171-192, 1975.

Such insensitivity is not exhibited, however, with respect to extreme differences. For example, assigning some weights of 0.0 and others of 1.0 has the effect of essentially deleting certain factors and highlighting others. Assignment of such weights will produce substantial changes in the ordering (as it should), for the model is highly sensitive to the factors included therein.

Insensitivity of a model to errors in weights is desirable. Insensitivity to differences among alternative systems in terms of several system parameters is undesirable. As is illustrated in Table 3-1, the SINCGARS Evaluation Model is sensitive to differences among alternative systems and permits identification of the reasons for the differences in utility. Table 3-1 also reflects another sensitivity analysis external to the SINCGARS Evaluation Model which involves the establishment of benchmarks that permit the interpretation of differences in utilities. In this case, an older family of radios (the AN/GRC 3-8, AN/PRC 9-11, and AN/ARC-44) of the Korean War era was evaluated. The utility values obtained for this series of radios provide a benchmark with which the utilities of the other alternative radio systems may be compared. This comparison provides a basis for such questions as:

> How does the improvement of this SINCGARS alternative over the current system compare with the improvement of the current system over the Korean War system?

Tables 3-2 and 3-3 present summaries of additional sensitivity analyses conducted with the SINCGARS Evaluation Model in which selected system parameters were varied throughout their particular ranges of values. These analyses permit the examination of the impact of the various parameters upon overall utility. For example, in Table 3-2, it may be observed that airborne communications planning range (ABNCPR) has a fairly minimal effect upon utility, while the retransmission capability (RETRAN) has a much greater effect. The results of an equal weights analysis of technical system utility are also presented in Table 3-2 and, as may be observed, the relative order of utilities does not change.

The general conclusion that was reached from the foregoing sensitivity analyses was that the SINCGARS Evaluation Model does perform as it should. It is fairly robust with respect to possible errors in assessing internal utilities and weights and, at the same time, it is externally sensitive, i.e., sensitive to differences in alternative systems.

Table 3-2

A SUMMARY OF INITIAL SENSITIVITY ANALYSES FOR THE TECHNICAL SYSTEM UTILITY PORTION OF THE SINCGARS EVALUATION MODEL

Sensitivity Analysis	Setting of the Values of Eight Selected Parameters[1]	Setting of the Values of All Other Parameters	Technical System Utility	
			Unequal Weights	Equal Weights
1	All to minimum	Alternative 1 levels	.14	.18
2	VEHCPR to maximum; remainder at minimum	Alternative 1 levels	.21	.21
3	VEHCPR & MANCPR to maximum; remainder at minimum	Alternative 1 levels	.33	.29
4	VEHCPR, MANCPR, & ABNCPR to maximum; remainder at minimum	Alternative 1 levels	.34	.29
5	VEHCPR, MANCPR, ABNCPR, & TOTALN to maximum; remainder at minimum	Alternative 1 levels	.48	.33
6	VEHCPR, MANCPR, ABNCPR, TOTALN, & ADJCHA to maximum; remainder at minimum	Alternative 1 levels	.54	.37
7	VEHCPR, MANCPR, ABNCPR, TOTALN, ADJCHA & RETRAN to maximum; remainder at minimum	Alternative 1 levels	.66	.51
8	VEHCPR, MANCPR, ABNCPR, TOTALN, ADJCHA, RETRAN, & INTERF to maximum; remainder at minimum	Alternative 1 levels	.79	.65
9	All to maximum	Alternative 1 levels	.81	.70
10	All to maximum	All to maximum	1.00	1.00

[1] With the following eight selected parameters:

- Vehicle CPR (VEHCPR)
- Manpack CPR (MANCPR)
- Aircraft CPR (AIRCPR)
- Total Channels (TOTALN)
- Adjacent Channel Interference (ADJCHA)
- Retransmission (RETRAN)
- Interface (INTERF)
- Burst Transmission (BURSTT)

Table 3-3

A SUMMARY OF SENSITIVITY ANALYSES FOR THE OPERATIONAL ACCEPTABILITY PORTION OF THE SINCGARS EVALUATION MODEL[1]

Sensitivity Analysis	Parameters Set at Their Best Levels	Parameters Set at Their Lowest Levels	Operational Acceptability Utility
1	All	None	1.00
2	All, except Flexibility	Flexibility	.72
3	All, except Flexibility and Survivability	Flexibility, Survivability	.53
4	All, except Flexibility, Survivability, Size, Weight, and Form Factor	Flexibility, Survivability, Size, Weight, and Form Factor	.39
5	All, except Flexibility, Survivability, and Physical Characteristics	Flexibility, Survivability, and all Physical Characteristics	.29
6	Transmission Quality	Flexibility, Survivability Physical Characteristics and Support	.19
7	None	All	0.00

[1]Flexibility in this table refers to operational flexibility

4.0 AN EVALUATION OF HARDWARE COST ESTIMATES

4.1 An Overview

In order to relate the military value or utility of the various alternative configurations of SINCGARS with the estimated costs of these alternatives, a 15-year life cycle cost (LCC) estimate was generated for each alternative utilizing an LCC model developed by the Army Electronics Command (ECOM). It was readily recognized, however, that whereas the estimated costs of Alternative 1 were based upon a wealth of experience in procuring those radios to date, the cost estimates of Alternatives 2, 3, and 4 involve considerable uncertainty. Moreover, in examining the various cost categories in the 15-year LCC model, it became apparent that the major cost element in the determination of the LCC of the alternative radio configurations is the average unit cost ($AUC) of the radios; i.e., the Hardware Cost Element of Recurring Investment which constitutes approximately 65% of the total program cost over 15 years. As a consequence and in the interests of creating greater confidence in just what the ultimate costs of each system might be, an interactive Monte Carlo program was developed.[1] The purpose of this program was to combine the probability distributions for the hardware $AUC of each radio for each platform (manpack, vehicular, and airborne) in proportion to the Authorized Acquisition Objectives (AAOs) of those radios/components. The outputs of this Monte Carlo program were:

- A probability distribution for the $AUC of each alternative radio system by platform. An illustrative distribution appears in Figure 4-1.

- A probability distribution for the $AUC of each of the radios and their ancillary components by platform. An illustrative distribution appears in Figure 4-2.

A summary of the outputs of this program reflecting not only the most likely $AUCs, but also the various combinations of radios, ancillary components, and AAOs is presented in Tables 4-1, 4-2, and 4-3.

4.2 Procedures and Output

Probability distributions for the average unit cost estimates associated with the various major components of the alternative SINCGARS were developed on the basis of elicitations from experts selected by the SINCGARS STF. The

[1] The Monte Carlo Program was developed under a contract sponsored jointly by the Defense Advanced Research Projects Agency (ARPA) and the Rome Air Development Center (RADC) and is described in a technical report entitled, Graphic Interactive System for Decision Theoretic Analysis by Decisions and Designs, Incorporated, December 30, 1974.

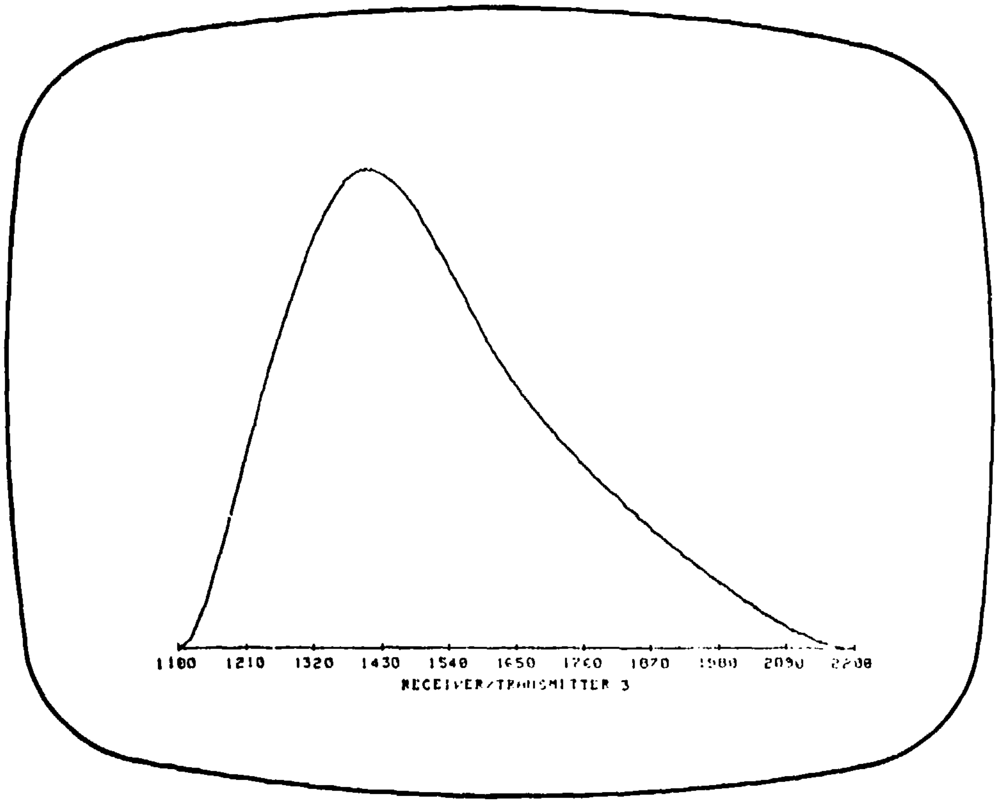


Figure 4-1

PROBABILITY DISTRIBUTION FOR THE $AUC OF RADIO SET AN/PRC-77, AS A MANPACK SUB-SET OF ALTERNATIVE 3[1]

[1] Also identified as the Receiver/Transmitter (R/T) for all of Alternative 3.

PERCENTILE	VALUE
0	1100
.01	11[illegible]3.06
.02	11[illegible]2.63
.03	1206.2
.04	1217.07
.05	[illegible]
.06	123[illegible].13
.07	1243.16
.08	1250.55
.09	1257.66
.1	1264.55
.11	1271.06
.12	1277.47
.13	1283.65
.14	1289.7
.15	1295.62
.16	1301.41
.17	1307.12
.18	1312.71
.19	1318.25
.2	1323.63
.21	13[illegible].06
.22	1334.37
.23	1339.63
.24	1344.83
.25	1349.93
.26	1355.03
.27	1360.15
.28	1365.19
.29	1370.17
.3	1375.14
.31	1380.05
.32	1384.97
.33	1389.85
.34	1394.72
.35	1399.58
.36	1404.42
.37	1409.27
.38	1414.12
.39	1418.97
.4	1423.83
.41	1428.7
.42	1433.6
.43	1438.5
.44	1443.44
.45	1448.41
.46	1453.4
.47	1458.45
.48	1463.52
.49	1468.69
.5	1473.87
.51	1479.13
.52	1484.4[illegible]
.53	14[illegible].95
.54	1495.41
.55	1501.02
.56	1506.63
.57	1512.4
.58	1518.18
.59	1524.12
.6	1530.03
.61	15[illegible].19
.62	[illegible]
.63	1[illegible]48.66
.64	[illegible]
.65	15[illegible]1.58
.66	15[illegible].73
.67	15[illegible].07
.68	[illegible].04
.69	15[illegible].22
.7	[illegible].55
.71	16[illegible].15
.72	1[illegible]12.[illegible]
.73	16[illegible].13
.74	[illegible].57
.75	1[illegible]37.3[illegible]
.76	1646.37
.77	1655.71
.78	1665.34
.79	1675.[illegible]
.8	1685.5
.81	1696.05
.82	1706.[illegible]
.83	17[illegible].06
.84	17[illegible].53
.85	1741.31
.86	1753.41
.87	1765.94
.88	[illegible].6
.89	1791.72
.9	1805.26
.91	1819.28
.92	1833.81
.93	1[illegible].98
.94	1865.0[illegible]
.95	[illegible]
.96	[illegible]
.97	[illegible]
.98	[illegible]
.99	[illegible]
1	2[illegible].08

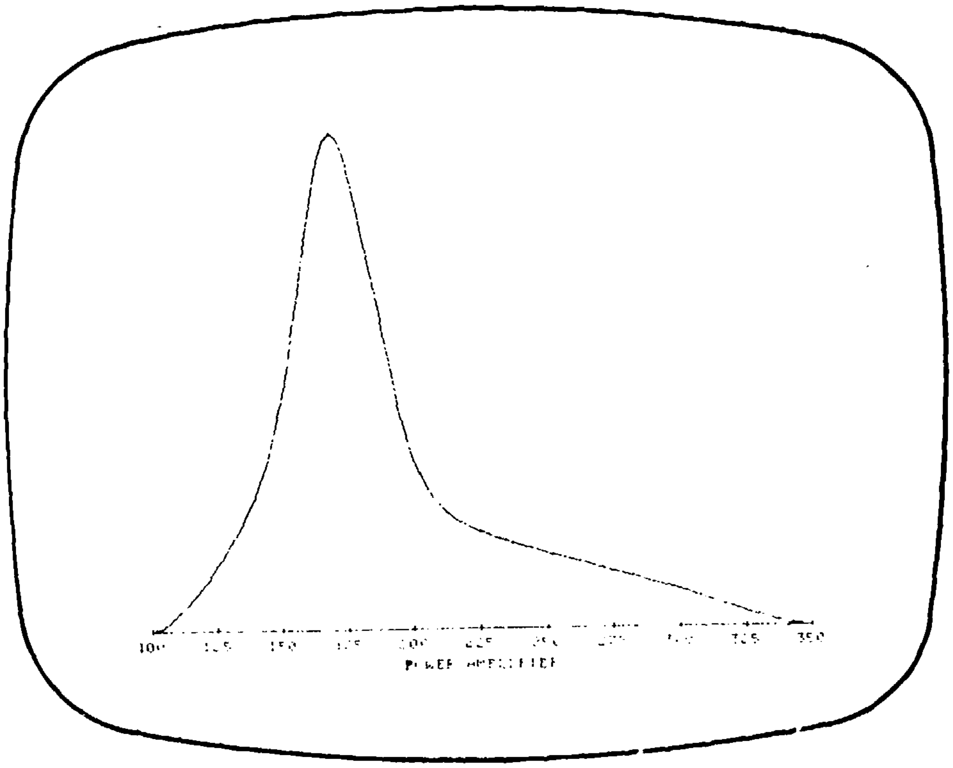


Figure 4-2

PROBABILITY DISTRIBUTION FOR THE $AUC OF THE POWER AMPLIFIER AS A MAJOR COMPONENT OF ALTERNATIVE 3

Table 4-1

A SUMMARY OF THE MOST LIKELY AVERAGE UNIT COSTS ($AUC) FOR ALTERNATIVE 2

Platform	Radio Sets[1]	Radio Sets and Major Ancillary Components[1]: AN/PRC-77	AN/GRC-160	RT-246	RT-524	R-442	Vehicular Antenna	Vehicular Mount	Aircraft Radio	AAO[2]	Most Likely $AUC
Manpack	AN/PRC-77	1								68,450	$ 870
	AN/GRC-160		1							43,160	1,415
										111,610	1,090
Vehicular	AN/VRC-12			1		1	1	2		6,103	5,170
	AN/VRC-46				1		1	1		48,188	2,540
	AN/VRC-47				1	1	1	2		23,254	[illegible],660
										77,545	3,190
Airborne	AN/ARC-114								1	12,780	3,980
Most Likely $AUC		$870	$1,415	$3,780	$2,350	$1,095	$154	$75	$3,980		

[1] Radio Sets: AN/PRC-77, AN/GRC-160, AN/VRC-12, AN/VRC-46, and AN/VRC-47
Receiver/Transmitters: RT-246 and RT-524
Auxiliary Receiver: R-442

[2] Authorized Acquisition Objective

Table 4-2

A SUMMARY OF THE MOST LIKELY AVERAGE UNIT COSTS ($AUC) FOR ALTERNATIVE 3

Platform	Radio Sets	Receiver/Transmitter (R/T) and Major Ancillary Components					AAO[1]	Most Likely $AUC
		R/T	Vehicular Applique	Vehicular Antenna	Power Amplifier	Aircraft Applique		
Manpack	AN/PRC-77	1					68,450	$1,420
	AN/GRC-160	1	1	1			43,160	1,880
							111,610	1,590
Vehicular	AN/VRC-12 & AN/VRC-47	2	2	2	1		29,357	4,130
	AN/VRC-46	1	1	1	1		48,188	2,225
							77,545	2,980
Airborne	Aircraft	1					12,780	1,990
Most Likely $AUC		$1,420	$300	$163	$320	$526		

[1]Authorized Acquisition Objective

Table 4-3

A SUMMARY OF THE MOST LIKELY AVERAGE UNIT COSTS ($AUC) FOR ALTERNATIVE 4

Platform	Radio Sets	Receiver/Transmitter (R/T) and Major Ancillary Components							AAO[1]	Most Likely $AUC
		R/T	Vehicular Applique	Vehicular Antenna	Antenna Coupler	Auxiliary Receiver	Power Amplifier	Aircraft Radio		
Manpack	AN/PRC-77	1			1				68,450	$1,290
	AN/GRC-160	1	1	1	1				22,892	1,850
	AN/VRC-64	1	1	1					20,268	1,700
									111,610	1,550
Vehicular	AN/VRC-12 & AN/VRC-47	1	1	1		1	1		29,357	2,920
	AN/VRC-46	1	1	1			1		48,188	2,070
									77,545	2,570
Airborne	Aircraft							1	12,780	1,970
Most Likely $AUC		$1,185	$360	$165	$190	$815	$365	$1,970		

[1] Authorized Acquisition Objective

elicitation process was facilitated through the use of an interactive computer program with a graphic display. For each of the major components of Alternative Systems 2, 3, and 4, the experts were initially requested to:

- Define the minimum feasible and maximum feasible costs.
- Trisect the range of costs between the minimum and maximum feasible so as to provide three intervals--intervals such that the probability that the cost of the particular component will fall in each interval would be the same, i.e., 0.333.
- Quadrisect the range of costs between the minimum and maximum feasible so as to provide four intervals--intervals such that the probability that the cost of the particular component will fall in each interval would be the same; i.e., 0.25.
- Define a 0.95 credible interval--an interval such that the probability that the cost of the particular component will fall in this interval would be 0.95.

The computer then displayed three probability distributions reflecting the foregoing inputs by the experts. Inconsistencies in these distributions were eliminated by virtue of direct interaction between the computer and the experts involving iterative adjustments of the distributions. As a result, a consensus was attained among the experts with regard to the probability distribution for the $AUC of each radio and major component. In order to combine these $AUCs, the Monte Carlo program sampled each of the probability distributions for the $AUC in accordance with the various combinations of radios/components and quantities (AAOs) shown in Tables 4-1, 4-2, and 4-3. A summary of the most likely $AUC for the three alternative systems by platform is provided in the table which follows:

Table 4-4

A SUMMARY OF THE MOST LIKELY $AUC BY ALTERNATIVE AND PLATFORM

Platform	Most Likely $AUC of Alternative Systems		
	2	3	4
Manpack	$1090	$1590	$1550
Vehicular	3190	2980	2570
Airborne	3980	1990	1970

The foregoing $AUCs were simply extracted from Tables 4-1, 4-2, and 4-3 and reflect the mix of radios and major components shown in those tables.

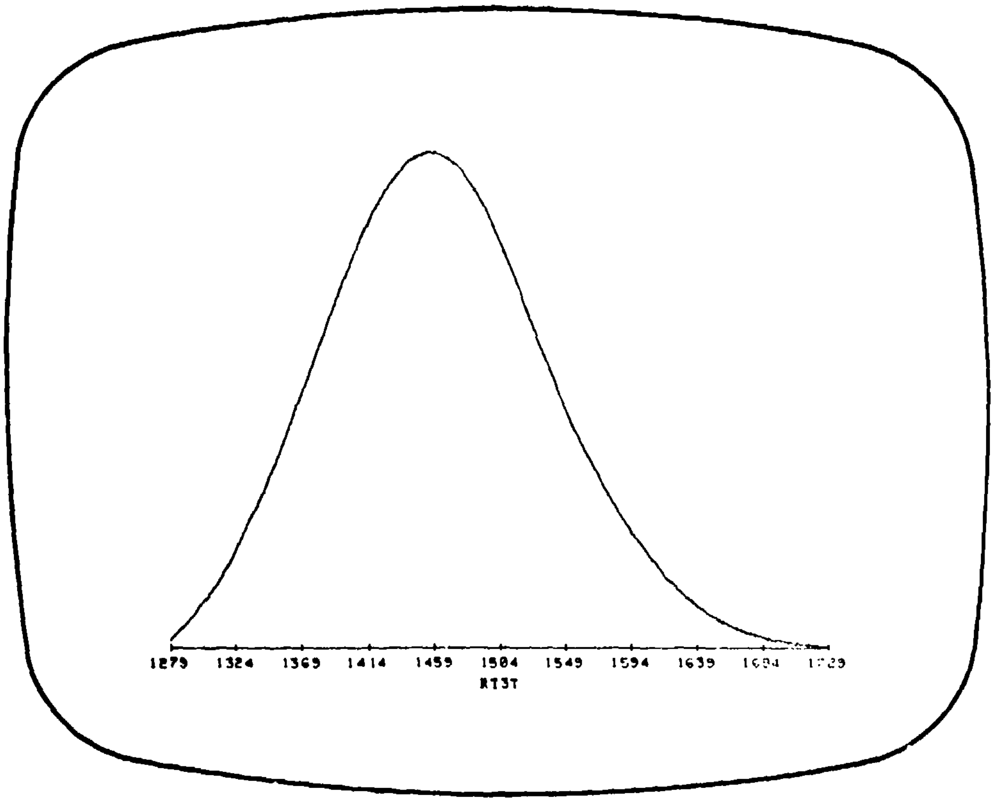
4.3 Observations

Still referring to Tables 4-1 through 4-4, it is apparent that Alternative 2 is the most costly system and Alternative 4 is the least costly system. Moreover, it may be observed that the primary difference between the $AUCs of Alternatives 3 and 4 is that of the vehicular radio. This difference may be attributed to the fact that the AN/VRC-12 and AN/VRC-47 combination for Alternative 4 employs an auxiliary receiver, whereas the corresponding combination for Alternative 3 uses two, rather than one, receiver/transmitters(R/T). The $AUC of this R/T is nearly $500 more than the auxiliary receiver of Alternative 4.

As may be noted in examining the probability distribution curves for $AUC, the curves do have different shapes. Hence, the modal value is a gross approximation which should not be used in isolation. For example, the most likely $AUC for the aircraft radio in Alternative 4 is less than the $AUC for the aircraft radio in Alternative 3. However, the resultant probability distribution for the $AUC of the aircraft radio in Alternative 3 is much more symmetrical than that of the aircraft radio in Alternative 4, which reflects a much higher probability of cost overrun.

As a cross-check on the assessment of the overall $AUC of the R/T for Alternative 3, probability distributions were assessed for the $AUC of each of the nine components that constitute the R/T of Alternative 3. The resulting distributions were combined using Monte Carlo procedures to obtain an overall distribution for the R/T $AUC of Alternative 3, which is shown in Figure 4-3.

Using this procedure, the most likely $AUC for the R/T of Alternative 3 is $1455, which corresponds rather closely with the R/T $AUC of $1410 in Table 4-2. However, as may be observed in Figure 4-3, the probability distribution for the R/T $AUC when the R/T is decomposed into its major components is much tighter--ranging from $1280 to $1730. The overall probability distribution for the R/T $AUC reflected in Figure 4-1 ranges from $1100 to $2200 and is also less symmetrical. By way of explanation, the usual result of combining the probability distributions for the $AUCs of many components of a system is that the resultant probability distribution is narrower than that obtained by assessing the probability distribution for the $AUC of the system as a whole. The reason for this is that an expert



PROBABILITY	VALUE
0	1279.27
.01	1303.6
.02	1321.37
.03	1330.52
.04	1337.94
.05	1344.16
.06	1349.68
.07	1354.66
.08	1359.21
.09	1363.41
.1	1367.33
.11	1371.03
.12	1374.55
.13	1377.38
.14	1381.04
.15	1384.1
.16	1387.06
.17	1389.88
.18	1392.63
.19	1395.29
.2	1397.88
.21	1400.42
.22	1402.87
.23	1405.3
.24	1407.64
.25	1409.97
.26	1412.22
.27	1414.47
.28	1416.65
.29	1418.83
.3	1420.95
.31	1423.07
.32	1425.15
.33	1427.21
.34	1429.25
.35	1431.28
.36	1433.28
.37	1435.27
.38	1437.25
.39	1439.21
.4	1441.17
.41	1443.11
.42	1445.05
.43	1446.98
.44	1448.9
.45	1450.82
.46	1452.73
.47	1454.64
.48	1456.56
.49	1458.47
.5	1460.38
.51	1462.29
.52	1464.21
.53	1466.14
.54	1468.06
.55	1470
.56	1471.94
.57	1473.9
.58	1475.87
.59	1477.84
.6	1479.84
.61	1481.84
.62	1483.88
.63	1485.91
.64	1487.99
.65	1490.08
.66	1492.2
.67	1494.34
.68	1496.52
.69	1498.74
.7	1500.99
.71	1503.28
.72	1505.61
.73	1507.99
.74	1510.44
.75	1512.92
.76	1515.49
.77	1518.1
.78	1520.82
.79	1523.61
.8	1526.49
.81	1529.48
.82	1532.57
.83	1535.77
.84	1539.15
.85	1542.67
.86	1546.36
.87	1550.24
.88	1554.35
.89	1558.72
.9	1563.4
.91	1568.44
.92	1573.91
.93	1579.33
.94	1586.52
.95	1594.04
.96	1602.81
.97	1613.47
.98	1627.41
.99	1648.69
1	1729.59

Figure 4-3

COMBINED PROBABILITY DISTRIBUTION FOR THE $AUC OF ALL COMPONENTS OF THE RECEIVER/TRANSMITTER OF ALTERNATIVE 3

will tend to be much more certain about the $AUC of each component of a system than he will be with respect to the $AUC of the system as a whole.

In this context, it is safe to assume that a similar tightening of probability distributions would occur if the R/T $AUCs for Alternatives 2 and 4 were decomposed into component $AUCs. Once again, the most likely $AUCs would tend to agree, but the decomposed probability distributions would have smaller ranges. Relying upon the broader overall probability distribution for the $AUC of a system (rather than the component probablity distributions), an expert may be quite certain that he has captured the relevant range of cost which, in essence, is a more risk-averse approach. In other words, when actual costs are assessed, the expert is less likely to be surprised.

5.0 RESULTS AND CONCLUSIONS

Having structured and tested the SINCGARS Evaluation Model as described in Section 3.0 of this report, the four alternative systems, as well as the Korean War system, were evaluated. The results of this evaluation appear in Table 5-1. In Table 5-2, not only are the values of technical system utility and operational acceptability shown for each of the alternatives, but also the values of the various sub-dimensions of these major dimensions. These utility values have been aggregated across all of the scenarios, environments, and platforms. In Table 5-3, the values of technical system utility and operational acceptability are presented for each of the alternatives as a function of aggregating the platforms across the scenarios and environments.

A complete tabulation of the utility values for technical system utility and operational acceptability at each node of the model from the sub-dimensional to the scenario levels were provided to the SINCGARS STF for each iteration of the model.

Table 5-1

A SUMMARY OF THE MILITARY VALUES OF ALTERNATIVE RADIO SYSTEM CONFIGURATIONS[1]

Major Dimensions of Value	Alternative Radio System Configurations				
	Korean War System (KWS)	Current System (Alt. 1)	Product-Improved System (Alt. 2)	Developmental System (Alt. 3)	Conceptual System (Alt. 4)
Operational Acceptability	.32	.69	.73	.74	.80
Technical System Utility	.03	.34	.39	.67	.65
Overall Military Value	.17	.51	.56	.71	.72

[1] Assuming that operational acceptability and technical system utility are weighted equally in determining overall military value.

Table 5-2

TECHNICAL SYSTEM UTILITY AND OPERATIONAL ACCEPTABILITY BY DIMENSIONS/SUB-DIMENSIONS FOR THE KOREAN WAR SYSTEM (KWS) AND ALTERNATIVES 1-4

Alternative	KWS	Alt.1	Alt.2	Alt.3	Alt.4
Technical System Utility	.03	.34	.39	.67	.65
Dependability	.08	.49	.53	.79	.78
Technical Performance	.34	.70	.73	.84	.83
Receiver-Transmitter Capability	.34	.80	.79	.88	.86
Retransmission Capability	.90	.90	.90	.90	.90
Channel Capabilities	.23	.76	.88	.92	.97
Interfact Capabilities	.19	1.00	1.00	1.00	1.00
Technical Flexibility	.46	.37	.37	.43	.51
Interchangeability	.00	.00	.00	1.00	.80
Electromagnetic Capability	.67	.70	.74	.52	.51
Operational Acceptability	.32	.69	.73	.74	.80
Operational Flexibility	.15	.87	.87	.87	.99
Survivability	.26	.41	.61	.62	.58
Physical Characteristics	.35	.69	.69	.75	.86
Support Requirements	.77	.87	.87	.88	.89
Transmission Quality	.34	.62	.62	.62	.62

Table 5-3

TECHNICAL SYSTEM UTILITY AND OPERATIONAL ACCEPTABILITY VALUES FOR ALTERNATIVES 1-4 AND THE KOREAN WAR SYSTEM (KWS) AS A FUNCTION OF PLATFORM

ALTERNATIVE	TECHNICAL SYSTEM UTILITY			OPERATIONAL ACCEPTABILITY		
	Manpack	Vehicular	Airborne	Manpack	Vehicular	Airborne
KWS	.05	.03	.00	.36	36	.29
1	.41	.27	.34	.68	.64	.77
2	.46	.32	.37	.72	.68	.81
3	.77	.59	.64	.74	.70	.81
	.76	.56	.66	.85	.73	.82

On the basis of the utility values displayed in Tables 5-1, 5-2, and 5-3, it is clear that Alternatives 3 and 4 are far superior to Alternatives 1 and 2. Most of this superiority is due to differences in technical system utility where the improvement of Alternative 3 over the current system, Alternative 1, is greater than the improvement of the current system over the Korean War System. Alternative 2 is not much better than Alternative 1 with respect to either technical system utility or operational acceptability.

As indicated in Table 5-2, the superiority of Alternatives 3 and 4 over Alternatives 1 and 2 are due to two factors, namely:

- The greatly improved dependability of Alternatives 3 and 4, and here it is important to bear in mind that technical system utility is a multiplicative combination of dependability and technical performance. The improvement in the dependability of Alternative 3 (and, similarly, Alternative 4) over Alternative 1 is about 50% of the improvement of the current system (Alternative 1) over the Korean War System (KWS). As previously indicated, the current system reflects the technology of about 1960, whereas the KWS reflects the technology of about 1950. The improvement of Alternative 3 over Alternative 1 is thus quite significant.

- The significant improvement in the technical performance of Alternatives 3 and 4. The improvement of Alternative 3 (and, similarly, Alternative 4) over Alternative 1 with respect to this factor is about 40 percent of the improvement of the current system (Alternative 1) over the KWS. This improvement, which is further discussed in Section 5.1, is due to improved receive/transmit capabilities, channel capabilities, and interchangeability.

The differences between the alternatives is not as great for operational acceptability. With respect to this dimension, Alternative 4 is better than Alternative 3, the latter being essentially equivalent to Alternative 2. The superiority of Alternative 4 over Alternative 1 is due to improved technical flexibility, improved survivability, and superior physical characteristics. The improvement of Alternative 4 over Alternative 1 is about 30 percent of the improvement of the current system (Alternative 1) over the KWS with respect to operational acceptability. The reasons for these differences among systems with respect to sub-dimensions of technical system utility and operational acceptability can be ascertained by examining the values of the systems with respect to the technical performance characteristics that describe the sub-dimensions. This was done and resulted in the technical conclusions which follow.

5.1 Technical Conclusions

- General comparisons

  - All of the alternative radio systems are essentially equivalent in terms of retransmission capabilities.

  - All but the older Korean War vintage radio system are essentially equivalent in terms of interface capabilities, support requirements, and transmission quality.

  - The alternative systems are much less variable in terms of operational acceptability than they are in terms of technical system utility.

  - There is little change in the relationships among the various alternative systems from the standpoint of scenarios (FEBA vs. non-FEBA).

  - All of the alternative systems are poor to unacceptable with respect to technical flexibility.

- Inter-system comparisons. Comparison of the alternative radio systems in pairs from the oldest (Korean War vintage) system to the developmental and conceptual designs indicates that:

  - In the case of the Korean War System (KWS) vs. System 1 (current series of radios):

    o System 1 is obviously far superior to the Korean War System in terms of operational acceptability for all environments and platforms. More specifically, System 1 is superior with respect to:

      -- Flexibility, due to its interoperability and COMSEC capabilities.
      -- Survivability, due to its anti-jamming capabilities.
      -- Physical characteristics, due to its size, weight, form factor, and human factors engineering.
      -- Transmission quality, due to its secure voice transmission capabilities.

    o System 1 is superior to the Korean War System in terms of overall technical system utility. More specifically, System 1 is superior to the KWS with respect to:

-- Dependability, which is multiplicative dimension.

-- Receive/transmit, interface, and channel capabilities.

o As a result of the foregoing comparison, it is concluded that the only change in importance weights that could make the Korean War System superior to System 1 would be to put all of the weight for technical system utility on technical flexibility. The Korean War System is otherwise a "dominated" alternative and therefore will not be compared further with the other alternative systems. However, it does serve as a good benchmark to initiate the comparison of the performance of the other alternative systems.

- In the case of <u>System 1 (current series of radios) vs. System 2 (product-improved version of the current series of radios)</u>:

  o System 2 is only slightly superior to System 1 in terms of both operational acceptability and technical system utility. This superiority is primarily due its dependability, channel capabilities, electromagnetic compatibility (EMC) and survivability.

  o As a result of this comparison, it is concluded that no changes in the importance weights or utility functions could make System 1 superior to System 2. Inasmuch as System 2 is a product-improved version of System 1, it is only natural that System 1 is a "dominated" alternative.

- In the case of <u>System 2 (a product-improved version of the current series of radios) vs. System 3 (a developmental radio system)</u>:

  o System 3 is slightly better than System 2 in terms of operational acceptability, primarily due to its physical characteristics of size, weight, visual detectability, and human factors engineering.

  o System 3 is far superior to System 2 in terms of technical system utility, primarily on the basis of the depen-

dability of System 3 (a dimension which is multiplied with technical performance to determine overall technical system utility). In addition,

- -- The overall technical performance of System 3 is superior to that of System 2.
- -- The receive/transmit (R/T) capability of System 3 is superior to that of System 2, primarily due to [illegible] communications planning range [illegible].
- -- System 3 is [illegible] superior to System 2 with respect to channel capabilities for an airborne platform and, to a lesser degree, with respect to the manpack platform. However, this superiority is reversed for the vehicular platform, due to the number of preset channels.
- -- System 3 is more technically flexible and is superior with respect to interchangeability.

o System 2 is superior to System 3 in terms of EMC, primarily due to its co-site and co-channel interference capabilities.

o In order to make System 2 superior to System 3 with respect to technical system utility, an extremely heavy weight would have to be assigned to R/T and heavy weights would also have to be assigned to those few sub-dimensions wherein System 2 is occasionally better than System 3; for example, as previously cited, channel capabilities. System 3 completely "dominates" System 2 with respect to operational acceptability.

- In the case of System 3 (a developmental system) vs. System 4 (a conceptual design), the best of the five alternative systems are compared and, generally speaking (given the current structure/output of the SINCGARS Evaluation Model), the differences between these two systems appear to be small. More specifically, however,

o System 4 is slightly superior to System 3 with respect to operational acceptability, primarily due to its COMSEC capabilities,

its manpack and vehicular physical characteristics (namely, visual detectability, form factor, and human factors engineering) and its operational flexibility. System 3, on the other hand, is superior to System 4 with respect to the survivability (direction-finding vulnerability) of its airborne radio.

- System 3 appears to be slightly better than System 4 with respect to technical system utility, primarily due to its manpack CPR and interchangeability. System 4, on the other hand, is superior to System 3 in terms of the R/T and variable power output capabilities of its airborne radio and also in terms of its channel capabilities and technical flexibility.

- System 3 could be made greatly superior to System 4 in terms of technical system utility by heavily weighting the R/T capability. On the other hand, System 4 could be made greatly superior to System 3 in terms of technical system utility by heavily weighting channel capabilities.

- With respect to operational acceptability, System 4 "dominates" System 3 in terms of all major dimensions except survivability. In order to reverse this superiority, survivability would have to receive a very heavy weight or the weights assigned to those sub-dimensions wherein System 3 is occasionally superior to System 4 would have to be systematically changed to favor System 3.

- Cost/Benefit Comparison. Combining the foregoing results of the evaluation of the military utility or benefit of the alternative radio systems with the results of the evaluation of hardware cost estimates in Section 4.0, the following conclusions were reached with regard to the relative cost/benefit merits of the alternative systems:

  - Inasmuch as Alternative 2 was far more expensive than either Alternative 3 or Alternative 4, the latter two alternatives are better options from a combined cost/benefit point of view.

  - Because Alternative 4 has a lower hardware cost that Alternative 3, and the military values of utilities of Alternative 3 and 4 are approximately equal, Alternative 4 is considered to be

the most cost/beneficial option. However, this conclusion must be qualified somewhat by the fact that the employment of two receiver/transmitters with Alternative 3, rather than an auxiliary receiver, increases its average unit cost ($AUC) by about $500.00. If this situation were rectified, Alternative 3 would compare quite favorably with Alternative 4 from a cost/benefit standpoint.

5.2 Methodological Conclusions.

5.2.1 General. The SINCGARS evaluation model has served to successfully differentiate among the four given alternatives and has shown that two are clearly superior. Furthermore, since the model is public with a definite structure, the reasons for the superiority of the systems are made clear by the model. In addition, "what if" analyses can be conducted to ascertain how changes in performance characteristics will lead to changes in utility. This allows not only the evaluation of other feasible SINCGARS alternatives not currently under consideration, but also the manipulation of various aspects of the conceptual system. To that end, the SINCGARS staff has been provided with a computer terminal which allows them to conduct additional "what if" analyses when they so choose.

Thus the SINCGARS Evaluation Model shows where changes in performance lead to the greatest changes in utility. Knowing the costs associated with such changes, the user can address not only the evaluation problem, but also the design problem. Evaluation models such as that used for this SINCGARS evaluation allow evaluation and design to proceed simultaneously. This is achieved by answering the general evaluation question, "What should a good radio system do?" as opposed to the more specific question, "What will these specific alternatives do?" Yet, at the same time, the output of an evaluation model allows specific recommendations with respect to the choice of alternatives to be made--as was the case with the SINCGARS Evaluation Model.

There are methodological implications of using an approach such as that which was used in the SINCGARS evaluation. One implication is that the structure of the model will differ somewhat from one which evaluates only predefined specific alternatives. The latter will not contain factors for which all systems are known to be the same. This is because the utilities for those factors will be equal across alternatives and will essentially be additive constants in the final overall utilities. It is argued that such constants obscure the "important" differences. However, when considering design problems where the alternatives are not completely certain, such factors must be included. The reason is that even on those dimensions where all systems are initially equivalent, the alternatives can change. For example, the conceptual system could be improved relative to the others, or a new system could be introduced.

5.2.2 Specific implications with respect to ranges of technical performance characteristics. The inclusion of the foregoing factors has implications for the ranges of technical performance characteristics over which utility functions will be assessed. When the alternatives are completely specified and will not change, the range of a technical performance characteristic is from the worst value with respect to that characteristic among the alternatives under consideration to the best value among those alternatives. When design considerations enter the picture and when "what if" analyses are to be conducted on an interactive basis, the range must be from the minimum feasible to maximum feasible values of that characteristic.

Close attention must thus be paid to the outputs at all levels of evaluation models. The inclusion of all factors relevant to utility implies that weights, utility functions, and even the structure are independent of the options under consideration. Utilities are relative only to some standard, as was true in the SINCGARS evaluation where that standard was the Korean War radio. Since the systems can be equivalent with respect to many factors of the model, the utility values for the alternatives are likely to be closer than they would be if only the specific systems were being evaluated.

5.2.3 Specific implications with respect to scenario usage. A second methodological implication involves the use of scenarios for system evaluation. Experts, when defining scenarios as conditioning variables that can cause variation in the performance of systems, usually choose variables which lead to variations in system performance but do not discriminate between systems because all systems vary in relatively the same manner with respect to these variables. Close attention must thus be given to the scenario definition process. Scenarios which simultaneously accomplish the following two goals are desirable:

- They must allow the evaluation of the expected utilities of the alternative systems.
- They must also discriminate among the various systems and thus identify special design issues.

These goals are rarely compatible and each has implications for scenario design. When these goals are incompatible, the user must decide which route to take with respect to scenarios. If the main goal is evaluation, broad representative scenarios, such as those used in this SINCGARS evaluation, allow calculation of overall expected utility. When design is the major consideration, as was not the case in this SINCGARS evaluation, highly specific scenarios must be used to discriminate between alternative designs and to locate optimum configurations.

As a result of the evaluative questions generated during this SINCGARS evaluation, as well as during other recent projects, close attention should be given to the scenario usage problem.

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San Diego, CA 92152

Human Factors Department (Code N215)
Naval Training Equipment Center
Orlando, FL 32813

Office of the Oceanographer of
the Navy
Attention: Dr. Andreas B. Rechnitzer
Hoffman Building II
200 Stovall Street
Alexandria, VA 22332

Training Analysis and Evaluation
Group
Naval Training Equipment Center
(Code N-00T)
Attention: Dr. Alfred F. Smode
Orlando, FL 32813

Technical Director
Naval Intelligence Support Center
4301 Suitland Road
Suitland, MD 20390

Director, Center for Advanced Research,
Naval War College
Attention: Prof. C. Lewis
Newport, RI 02840

Dean of the Academic Departments
U.S. Naval Academy
Annapolis, MD 21402

Chief, Intelligence Division
Marine Corps Development Center
Quantico, VA 23701

Department of the Air Force

Deputy Assistant Chief of Staff for
Studies and Analysis
Department of the Air Force
The Pentagon, Room 1E388
Washington, DC 20330

Assistant for Requirements Development
and Acquisition Programs
Office of the Deputy Chief of Staff for
Research and Development
Department of the Air Force
The Pentagon, Room 4C331
Washington, DC 20330

Air Force Office of Scientific Research
Life Sciences Directorate
1400 Wilson Boulevard
Arlington, VA 22209

Director, Air University
Maxwell AFB, AL 36112

Dean of the Academic Departments
U.S. Air Force Academy
Colorado Springs, CO 80840

Director of Intelligence Applications
Headquarters, Air Force Systems Command
Andrews AFB
Washington, DC 20331

Chief, Systems Effectiveness Branch
Human Engineering Division
Attention: Dr. Donald A. Topmiller
Wright-Patterson AFB, OH 45433

Director, Foreign Technology Division
Wright-Patterson AFB, OH 45433

Chief Scientist
Air Force Human Resources Laboratory
Attention: Dr. Howard L. Parris
Brooks AFB, TX 78235

Aerospace Medical Division
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Attention: Lt. Col. John Courtright
Brooks AFB, TX 78235

Commander, Rome Air Development Center
Attention: Mr. John Atkinson
Griffiss AFB
Rome, NY 13440

IRD, Rome Air Development Center
Attention: Mr. Frederic A. Dion
Griffiss AFB
Rome, NY 13440

Director, Advanced Systems Division(AFHRL/AS)
Attention: Dr. Gordon Eckstrand
Wright-Patterson AFB, OH 45433

Other Government Agencies

Chief, Strategic Evaluation Center
Central Intelligence Agency
Headquarters, Room 2G24
Washington, DC 20505

Director, Center for the Study of
Intelligence
Central Intelligence Agency
Attention: Mr. Dean Moor
Washington, D.C. 20505

Office of Life Sciences
Headquarters, National Aeronautics and
Space Administration
Attention: Dr. Stanley Deutsch
600 Independence Avenue
Washington, DC 20546

Other Institutions

The Johns Hopkins University
Department of Psychology
Attention: Dr. Alphonse Chapanis
Charles and 34th Streets
Baltimore, MD 21218

Institute for Defense Analyses
Attention: Dr. Jesse Orlansky
400 Army Navy Drive
Arlington, VA 22202

CTEC, Incorporated
Attention: Mr. Harold Crane
7777 Leesburg Pike
Falls Church, VA 22043

Director, Social Science Research Institute
University of Southern California
Attention: Dr. Ward Edwards
Los Angeles, CA 90007

Perceptronics, Incorporated
Attention: Dr. Amos Freedy
6271 Variel Avenue
Woodland Hills, CA 91364

Director, Human Factors Wing
Defense and Civil Institute of Environmental Medicine
Attention: Dr. C. H. Baker
P.O. Box 2000
Downsville, Toronto
Ontario, Canada

Columbia University
Department of Psychology
Attention: Dr. Eugene Galanter
New York, NY 10027

Stanford University
Attention: Dr. R. A. Howard
Stanford, CA 94305

Integrated Sciences Corporation
Attention: Mr. Gary W. Irving
1532 Third Street
Santa Monica, CA 90401

Mr. Luigi Petrullo
2431 North Edgewood Street
Arlington, VA 22207

Montgomery College
Department of Psychology
Attention: Dr. Victor Fields
Rockville, MD 20850

General Research Corporation
Attention: Mr. George Pugh
7655 Old Springhouse Road
McLean, VA 22101

Grumman Aerospace Corporation
Attention: Mr. J. W. Stump
Bethpage, NY 11714

Oceanautics, Incorporated
Attention: Dr. W. S. Vaughan
3308 Dodge Park Road
Landover, MD 20785

Journal Supplement Abstract Service
American Psychological Association
1200 17th Street, N.W.
Washington, DC 20036
(three copies)

Director, Applied Psychology Unit
Medical Research Council
Attention: Dr. A. D. Baddeley
15 Chaucer Road
Cambridge, CB2 2EF
England

Department of Psychology
Catholic University
Attention: Dr. Bruce M. Ross
Washington, DC 20017

Stanford Research Institute
Decision Analysis Group
Attention: Dr. James Matheson
Menlo Park, CA 94025

Hebrew University
Department of Psychology
Attention: Dr. Amos Tversky
Jerusalem, Israel

Human Factors Research, Incorporated
Santa Barbara Research Park
Attention: Dr. Robert R. Machie
6780 Cortona Drive
Goleta, CA 93017

University of Pennsylvania
Wharton Schoo
Attention: D . H. L. Morgan
Philadelphia, PA 19174

Oregon Resea h Institute
Post Office ox 3196
Attention: r. Paul Slovic
Eugene, Oregon 97403

Eclectech Associates, Incorporated
Post Offic Box 179
Attention: Mr. Alan J. Pesch
North Stonington, T 06359

University of Michigan
Department of Electrical and Computer
Engineering
Attention: Professor Kan Chen
Ann Arbor, Michigar 94135

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Introduction. This report reflects the development, validation, and utilization of a multi-attribute utility model for use by the SINCGARS STF in comparing/evaluating the military utility of a series of alternative radio systems. The model was programmed to be interactive and was made available to the SINCGARS STF in order to enable the STF to conduct additional analyses.

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This report also reflects the development and utilization of an interactive Monte Carlo program for the evaluation of alternative hardware cost estimates.

Background and Approach. The objectives of the research described in this report were to:

- Develop and test a multi-attribute utility model which was used to assist the SINCGARS STF in evaluating the military utility of alternative Combat Net Radio configurations. Of particular importance during the development of the model was the need to provide an analytic tool which would accept "last minute" changes in data and would also enable a user to conduct "what if" analyses on an interactive basis. The multi-attribute utility model which was developed utilizes the technical performance characteristics of the radio systems as inputs.

- Develop and apply an interactive Monte Carlo program for evaluating the hardware cost estimates of the alternative systems.

A hierarchical structure for the multi-attribute utility model consisting of several levels was developed, starting with military utility and partitioning this into major dimensions of utility, e.g., technical system utility and operational acceptability. These dimensions were further sub-divided into sub-dimensions which, in turn, were further partitioned--each partition becoming more specific until a level was reached at which one or more technical performance characteristics served to describe each of the sub-dimensions. The military utility for different levels of each of the performance characteristics was established by assessing a utility function over the relevant range of that characteristic. The relative importances of the different performance characteristics were assessed by assigning relative importance weights to the components of each level of the hierarchy. The procedures for assignment depended upon how the components combine to determine system utility at the level in question. Combination rules (additive or multiplicative) were then applied to aggregate the utilities for the components both within and across the various levels of the hierarchy.

The resultant structure thus systematically combined expert judgment and technical performance characteristics to provide a model which accurately aggregated the actual measures of the performance characteristics of a particular system so as to yield a measure of the military utility of the system.

The Monte Carlo program was used to develop a probability distribution for the $AUC of each of the radios and its ancillary components. These were then combined to yield probability distributions for the overall $AUCs by platform for each alternative system.

Findings and Implications. Having structured and tested the SINCGARS Evaluation Model as previously described, the model was used to evaluate four alternative radio systems, as well as a Korean War System (KWS) which served as a benchmark for comparison of utilities. As a result of this evaluation, two alternative systems were identified as being superior to the others from the standpoint of military utility. Similarly,

utilizing the Monte Carlo program, one of the alternative systems was identified as being the least expensive in terms of hardware costs. Combining the foregoing results of the evaluation of the military utility or benefit of the alternative radio systems with the results of the evaluation of hardware cost estimates, one of the alternative radio systems was identified as the best cost/beneficial option.

The two most important methodological implications for the application of decision analysis which were derived from the foregoing evaluation involve appropriate definition of the:

- Range of technical performance characteristics to be used in the analysis.
- Scenarios for design and evaluation decisions.